FORGING A HEAVY SHAFT UNDER A STEAM DROP HAMMER

Courtesy of Bethlehem Steel Corporation

FORGING AND FORMING METALS

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PREFACE

The pace of modern technological progress in America is unrivaled the world over. Contributing mightily to that progress stand the improvements in method and innovations in technique that have come from the shops and research laboratories of the nation's industries. In the march toward goals of better production, the forging industry has been notably active.

As new uses for various metals multiplied, and as the superior qualities imparted to metals by forging came to be more positively recognized, the forging industry accelerated its efforts to produce more and better products at diminishing cost. Through development and adaptation it succeeded.

At present, abundant opportunities exist for persons with "know-how" and "know-why" of the processes used in this field of metal forming. This book is dedicated to the end that a fuller understanding of these processes may be had by many.

Rapid expansion of the industry, development and improvement of new machines and methods, and the introduction of new products place a premium on an extensive knowledge of forging processes. The basic employee, the shop foreman, plant supervisor, technician, engineer, and executive in any metal-working industry who has such knowledge—and who applies it for the maximum benefit of his organization—will himself reap tangible rewards.

Impact forging, press forging, upset forging, extrusion, heat treatment of forgings, cleaning and finishing of forgings, inspection of forgings, safety in the forge shop, designing a forged part, designing dies and tools, metal quality, and selection of a metal for forging are all described thoroughly in this book. Each subject is covered as a separate unit, thus providing a flexibility which will permit selection or integration of the book's contents to meet specific needs and individual requirements.

A Glossary of Forging Terms and a chapter entitled "Standard Practices and Tolerances for Impression Die Forgings" are included. The usages and specifications set forth in these sections are in accordance with those adopted by the Drop Forging Association. An Appendix of Useful Tables and a selective Bibliography are provided at the end of the text.

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S. E. RUSINOFF

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CHAPTER 1

Introduction

Development of an Ancient Mechanical Art. The plasticity of a metal is the property by which a metal may be altered in shape, permanently and without rupture. It is a property of the highest importance. The application of heat increases the plasticity of metals to a large extent, thus making it possible to conduct the operations necessary for the fabrication of various products. Among such operations, forging occupies a prominent place.

The art of forging metals dates back many centuries, having been developed with the earliest discovery of metals. Only scant information regarding the ancient methods of making tools and weapons from metals is available from historical records. However, it is definitely known that in the earliest days of civilization, as well as in modern times, iron was the basic metal used. It is also true that other metals, such as copper, gold, and silver, were known and used before iron. However, they were not used to the same extent as iron, probably because of the greater abundance of the latter metal among the natural resources of mankind.

The early application of the art of forging probably consisted of hammering pieces of metal between rocks as a means of devising the crude weapons and tools needed by man in those days. Biblical references suggest that the ancient inhabitants of Western Asia were the earliest users of iron and other metals. It, therefore, may be deduced that they also introduced the art of forging the metals in their possession into useful implements. The ancient Greeks were probably the next in order to utilize the art of forging for the purpose of shaping the available metals into various weapons and tools. Ancient records, pieced together, show that India and China also had knowledge of iron and even steel at a very early historic age. The art of hammering these metals, after they have been heated at an improvised forge, was well known by craftsmen in India. Some very fine weapons, such as swords and knives, were skillfully hammered to shape by those men after they had heated metals to temperatures which assured them sufficient plasticity. Ancient craftsmen even knew the art of heat treating metal implements fashioned by them by heating the metal and then quenching it in a liquid, thus obtaining the required hardness. Illustrative examples of ancient craftsmanship are the still famous swords of Damascus, Toledo, and Balboa.

In the early days of our civilization, the art of forging was principally used for the purpose of fashioning implements of war, such as swords, knives, protective armour, helmets, and like articles. Iron and steel were the basic metals worked by the craftsmen, and the tools they used were very primitive. After the twelfth century, there was a definite trend toward the improvement of the tools the craftsman used in order to fashion implements of better physical quality and precision. The old primitive forge, wherein metals were heated, gave way to a forge employing a blast of air, by means of which intense heat was rapidly developed and utilized for the uniform heating of metals before hammering.

Forging hammers have also undergone a constant development with the introduction of forged parts of larger sizes and of more complex shapes. The hand sledge was the principal tool supplying the power for many centuries, and it still is used for occasional hammering of comparatively small objects. Nevertheless, the need for greater power to forge larger and more intricate objects created a demand for more advanced hammer equipment which could successfully shape the required products. Mechanical hammers came into the picture to supply the necessary power. Of course, only improvised power hammers were used at first, but constant development and continued improvement finally resulted in the modern power equipment used in the forging industry today.

The evolution of the power hammer was at first rather painfully slow, but with the advent of the nineteenth century, progress in the design of the power hammer was greatly accelerated. Nevertheless, hammering has not been the only method of forging metals into various shapes wherein progress has taken place. A number of other methods of working heated and nonheated metals have been introduced and improved upon in recent years. As a result, a great variety of forged products have appeared in numerous applications.

Forging as a Basic Manufacturing Process. The widely used manufacturing process, known as forging, is a basic process. It primarily consists of working a piece of metal, usually hot, to a predetermined shape by one of the available forging methods. Depending upon the type, size, shape, and physical requirements of the product, a number of forging methods are at the disposal of the product manufacturer. These are hammering, upsetting, pressing, extrusion, or a combination of several of these methods. Selection of a basic process of forging is determined by two chief requirements—first, production of an object of a specified shape, and second, improvement of the physical properties of the metal by forging. Other important advantages derived from a product fabricated initially by means of forging are as follows:

1. When designing the required part, the engineer has considerable freedom because of a wider range of materials at his disposal to meet specific demands in service.
2. Since forged parts have ample strength to resist external forces, the use of parts of lighter sectional thickness is permitted, thus considerably reducing the dead weight of these parts.
3. Forging a part to the required shape also produces in the part the desired combination of physical properties in the correct proportion, thus insuring maximum strength and toughness, properties so vital in service.
4. Thoughtful and careful design of proper tools results in accurate shaping of parts with the least amount of allowance for finishing, thereby reducing substantially the cost of final machining.

Modern plastic shaping of metals still uses externally applied force, but the art is practiced with the aid of scientifically designed tools, among which is a drop hammer capable of striking an impact blow of 10,000 tons, and mechanically or hydraulically operated presses capable of applying pressures as great as 20,000 tons. Such tools make it possible to manufacture products of very great variety and of almost every conceivable size. An assortment of closed-impression die forgings weighing from less than an ounce to several hundred pounds are shown in Fig. 1.

Before modern mass-production techniques were developed, metals were heated in suitable forges and then hammered into shape on an anvil by a smith, who used various hand-forging tools to shape

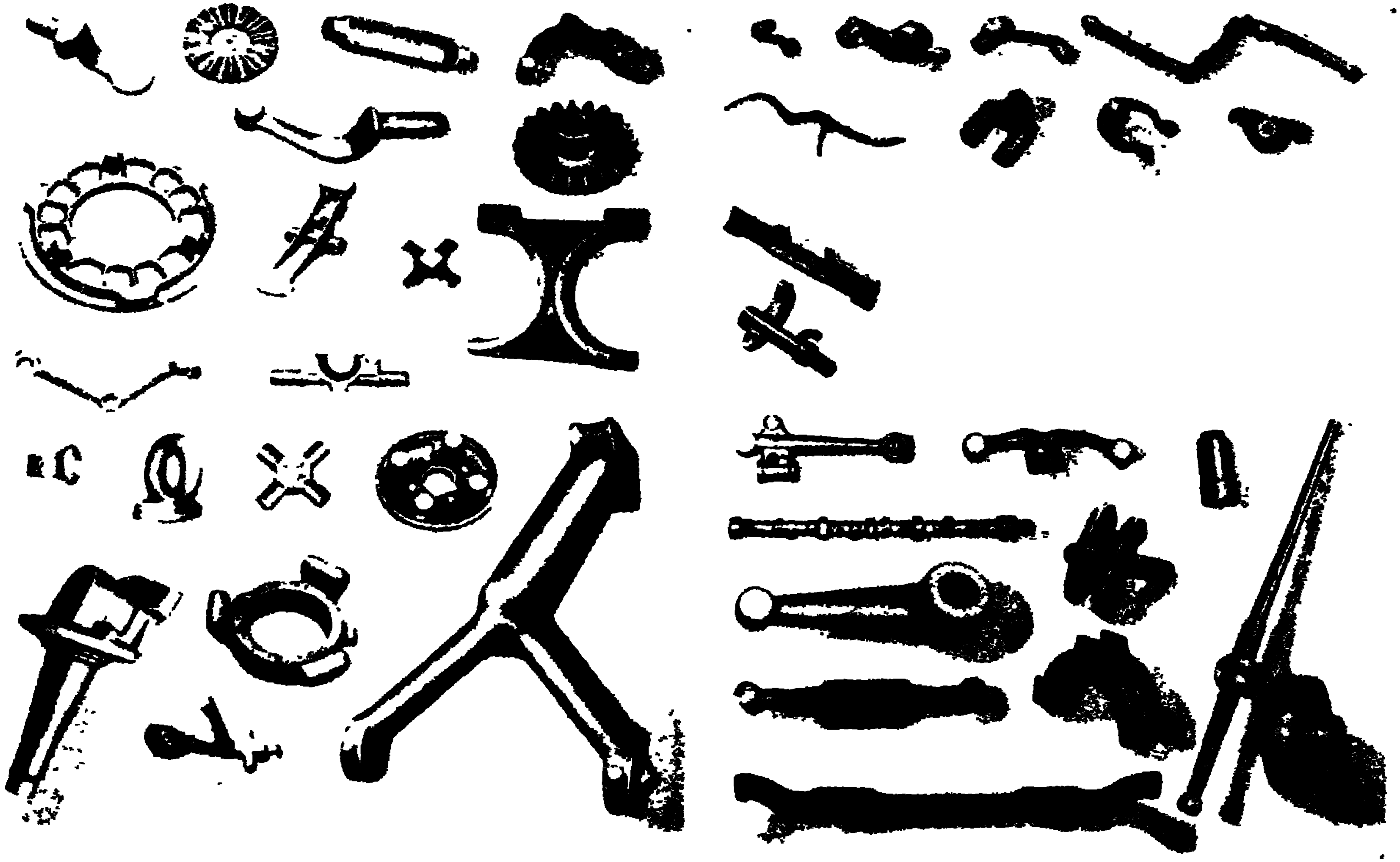


Fig. 1. Variety of Closed-Impression Die Forgings

Courtesy of Drop Forging Association, Cleveland, Ohio

the work. This age-old procedure is still followed where limited quantities of forged pieces are desired, as in shop-maintenance work, railroad repair shops, etc. The equipment required for such work costs relatively little. However, in most shops where forging is done, hand forging has gradually been abandoned, and the work is performed by power-operated hammers instead. Inevitably, the old forges used for heating metals yielded place to modern furnaces.

Power hammers of various types are not only suitable for forming objects of definite shape, but are especially adaptable for shaping steel sections which require a considerable reduction in cross-sectional area, with or without definite form changes. The work performed is similar to hand forging in every respect, except that the tools are manipulated by power which may be belt-driven or operated directly by air, fluids, or steam. Only flat dies are used.

Application of Forging in Modern Production. Metals in general, steel in particular, which are among the most basic engineering materials of this day, must frequently meet excessively rigid requirements for strength and toughness in order to be useful in the numerous applications existing in modern industry, where high speed and power and mass production are of vital importance. Both the manufacturer and the user of the manufactured product are greatly concerned and interested in the improvement of the physical qualities of metal which is shaped into required products. The forging process not only shapes the product, but continues throughout the entire production cycle to further develop the maximum strength and toughness of the metal—the metal is literally kneaded into a dense mass of strength and toughness.

The forging process widely adapted in modern production has undergone vast technological changes throughout the ages. Therefore, instead of being a rigid process using the same technique in all industrial applications, it may be considered as a basic manufacturing process composed of several methods. The choice of a suitable method will, of course, depend upon the specific type of product wanted and upon the judgment and experience of the designer and production engineer.

Forging, as adapted to production in modern manufacturing industry, consists of four principal methods. Each method prescribes ways of shaping metal into required forms—predominantly by hot working. These methods are as follows: smith forging, drop forging, press forging, and machine or upset forging. According to an estimate of the Drop Forging Association, which represents most of the companies of the commercial drop-forging industry, at least 80 per cent of the total tonnage of forgings produced by the industry is forged by the drop forging method. Fig. 2 shows a steam drop hammer designed for forging airplane parts. The entire machine weighs over 500 tons, and the weight of the hammer, itself, is 50,000 pounds. Closed-impression dies, which are explained in succeeding pages, are used for accurate shaping of the parts. Similar hammers are also used for forging automotive parts and other numerous products required in various manufacturing industries.

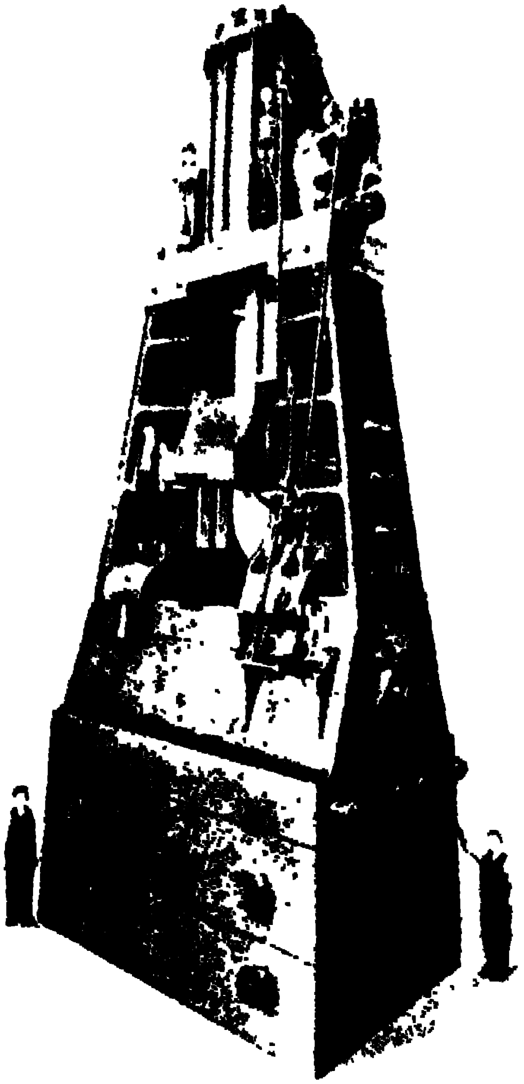


Fig. 2 Steam Drop Hammer for Forging Airplane Parts

Courtesy of Erie Foundry Company, Erie, Pa

Whichever method is selected, the worked metal undergoes a specific degree of improvement. The choice of the best method for a particular product is affected by numerous factors, and it is therefore recommended that consultation with a competent forging engineer be seriously considered as a preliminary step in ascertaining what shall constitute the selection of a proper forging method and technique for a particular task. Smith forging consists of forming the hot metal with the aid of flat or open-faced dies, as is explained in succeeding pages. Drop forging, press forging, and machine or upset forging employ closed-impression dies for forming the hot metals into specific shapes. The use of closed-impression dies secures a vitally important advantage in the hot working of metals, particularly steel. The working of hot steel in these dies utilizes to the utmost the fiber structure inherent in the steel, and concentrates the grain density and fiber formation at predetermined points of greatest shock and stress.

Many types of metals are suitable for the stated forging methods. The common metals used for drop forging are: steel (0.10 per cent to 0.50 per cent carbon), wrought iron (used very little owing to its lack of strength), copper-base alloys, aluminum alloys, and magnesium alloys. Steels containing a higher content of carbon than the percentages just mentioned are used for forging products that are required to possess special physical properties. The tables in the Appendix of this text give an indication as to what the designer can expect from these metals. Included under the steels are the suggested National Emergency steels which can be used when certain alloy steels are difficult to obtain.

REVIEW QUESTIONS

1. Explain the meaning and importance of plasticity of a metal.
2. What was the principal purpose of forging metals in the early days of our civilization?
3. Name some of the forging equipment used in early days.
4. Give two reasons for selecting forging as a basic manufacturing process.
5. What is the maximum impact blow that modern drop hammers are capable of striking?
6. What is the maximum pressure that modern forging presses can apply?
7. Name four principal forging methods as adapted to production.
8. Explain briefly each forging method named in your answer to Question 7.
9. Explain briefly the importance of a forging engineer in selecting a suitable manufacturing method.
10. What are the qualifications of a forging engineer?
11. Name five stages of production at which the technical guidance of a forging engineer is most valuable to a manufacturer.

CHAPTER II

Metal Quality

The Usefulness of a Metal in Service. The real quality of a metal is measured by its usefulness when called upon to meet specific service requirements. These requirements are quite rigid in many present-day machines, mechanisms, devices, and appliances. When designing products for various uses, the engineer must exercise his knowledge of materials and manufacturing experience to assure these products dependable and safe performance and long life in useful service. In selecting a proper metal, the designer first ascertains the satisfactory behavior of the metal under those stresses which are likely to occur in service. Modern technological development of metals and the existence of abundant information about them ease the task of selecting an appropriate metal for a given job.

Of course, only certain properties and qualities of a particular metal are indicated in the available information. It has been a common practice to judge a metal by the predominant physical property it possesses, for example, its tensile strength. The existence of a high tensile strength in a metal was supposed to be indicative of the existence of other desirable physical properties in the same measure, properties which must be present in the metal if it is to be useful in service. It is true that numerous tables and charts give essential information on the various properties of metals, but that information is of greater value to the metallurgist rather than to the designing and production engineer. The latter, in many cases, is not too familiar with the terms in which the data is presented.

In order to satisfy a specific service condition and be useful, the metal chosen by the designing engineer must have real metal quality, i.e., it must possess a suitable combination of physical properties. In this respect, the metallurgist and the engineer are in mutual agreement, since neither one of them will base his final acceptance of the suitability of the metal upon only one predominant physical property, such as tensile strength. Yet, each one will approach his subject from a different angle.

Let us take, for example, a manufactured product which may be subjected in service to commonly existent stresses. These stresses may be either static or dynamic ones, or a combination of both. Selection of a suitable material for a stress-resistant component part of a product is governed by intelligent knowledge of the stress conditions and stress distribution on the particular part in service. This knowledge of stress conditions is obtained by careful stress analysis. A specific grade of metal may be satisfactory for one type of service, but it may be deficient for another. Dimensionally, a particular part may fit within either of two assemblies as a component shaped for the same function (action). A crankshaft forged or cast from a particular type of steel may be highly satisfactory for one type of engine, but it would not meet the rigid requirements of another type of engine. The selection of a suitable metal should be based upon a careful analysis of all possible stresses involved in each case. Where unfailing performance is a matter of high importance, such as in automotive and aircraft operating mechanisms, the analysis should be followed by subsequent determination of actual stresses in an experimental product—one built before actual production on a large scale is started.

Many engineering materials, particularly commonly used metals, may have a predominant physical property, such as high tensile strength, but this physical property is of minor value unless it exists in a balanced combination of other physical properties. A product made of hardened, high-carbon steel may have a very high tensile strength but have no ability whatsoever to safely deform in actual service. A product made of such material has no value to function as a structural member of an operating mechanism within a machine or engine, because its high tensile strength is not properly balanced with other properties which are capable of meeting the combined stresses to which this structural member is subjected. A limited-property material, for example, is a file-hard carbon steel having a tensile strength amounting to over 300,000 pounds per square inch, but having no ability to deform in useful service. Use of such a material in an operating mechanism subjected to stresses which an experienced engineer knows of being present in the product involved would be dangerous. These stresses are: bending, torsion, and impact. Fig. 1 demonstrates this condition.

Some materials, such as certain types of glass, possess extreme hardness. This predominant physical property makes these materials available and very useful in many practical industrial applications. Other types of glass and other materials possess a high degree of elasticity as a predominant physical property. *Elasticity* may be defined as the ability of a material to fully resume its former shape after having been deformed in actual service. Among the metals, steel possesses a high degree of elasticity, although it may not possess quite as much as special types of glass and other materials. Glass retains its elasticity and toughness up to what is known as the *elastic limit.* Upon reaching a range immediately past this limit, the glass will not sustain its previous properties of elasticity and toughness and will, therefore, break. However, different conditions will prevail if steel is subjected to stresses beyond its elastic limit. It will not fail if these stresses are not too excessive. The ability of steel to absorb a considerable amount of energy due to its physical structure permits a considerable amount of plastic flow before it reaches a point of ultimate failure.

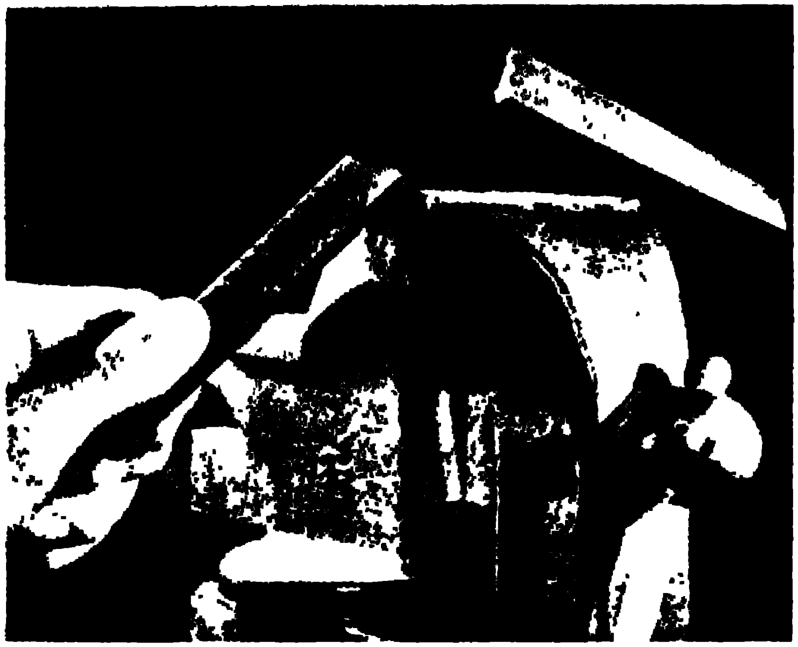


Fig. 1. Action Showing That a File-Hard Carbon Steel Has Very Little Ability To Deform in Useful Service

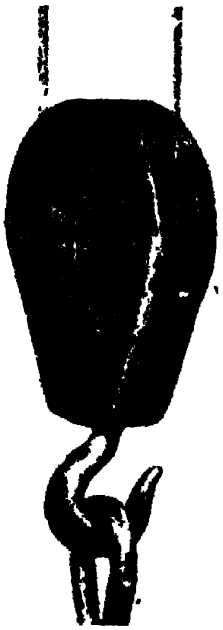


Fig. 2. A Stress-Absorbent Forged Steel Hook

Courtesy of Drop Forging Association, Cleveland, Ohio

Other important features of predominant physical properties possessed by materials, which are indicative of the ability of the material to perform in useful service, are the degree of impact resistance, metal flow (an important property in forming and shaping), resistance to corrosion, etc. A properly proportioned combination of several stresses to which the manufactured product is subjected is what governs the selection of the best material for the product in order for it to behave satisfactorily in useful service. The designing engineer can now proceed and calculate the dimensions for the required product, providing he is also satisfied with the manufacturing method decided upon to produce the particular part in question. Calculated dimensions for the part may be altered considerably if a selected manufacturing method is unavailable for some reason, and another method is decided upon. An example of a change in production method would be a change from casting to forging, or vice versa. The dimensions and shape of a part to be produced by one method will be changed considerably if another method is selected. Furthermore, the method used in producing the required part frequently alters completely the combination of physical properties existing in the part, although the material from which it is produced may be identical in each case.

A very important physical property in an engineering material is that of toughness. This property may be defined as a measure of the capacity of the material to absorb the total energy developed in service. Toughness also includes the degree of elastic and plastic deformation of the material under consideration. There is a definite relationship between the toughness of a material and its ability to resist shock loads or sudden blows—a characteristic we call impact strength. Fig. 2 shows a crane hook—a product that must have a great deal of toughness if it is to meet successfully the service demands made of it. Products of the same type as the crane hook are subjected to considerable loads and are required to absorb much of the developed energy before the product materials undergo plastic deformation. One predominant physical property in the material is not sufficient to resist the external loads applied in service, but a balanced combination of several physical properties providing real toughness will insure against failure. The proper choice of a manufacturing process, which is forging in the case of the crane hook, is very important, since it further improves the combined physical properties of the part under consideration by working the metal to the required shape and strength.

The Ingot Predetermines the Future Quality of Steel. The first industrial form of all metals, except nonsolids and those shaped directly from a powder state, is a casting. This is especially true of steel. A metal is first heated to a liquid or molten state in a suitable furnace, and is then poured into suitable sand or metal molds in which solidification takes place. When solid, the cast forms or ingots are stripped from the molds and reduced to semifinished or finished forms by mechanical working—either hot-working or cold-working operations. Fig. 3 illustrates the operation of ladling or pouring molten steel into molds. A huge ladle with liquid steel is carried by an overhead crane to positions above a row of cast-iron ingot molds. The molten metal is poured into the molds from the bottom of the ladle.

The steel ingot is virtually the foundation form of every quality of steel. Molten steel is substantially a homogeneous liquid composed of iron in combination with carbon, manganese, silicon, sulphur, and phosphorus. Special steels may contain, in addition, various percentages of chromium, vanadium, tungsten, molybdenum, nickel, aluminum, and other elements which enhance certain physical properties, such as hardness, toughness, ductility, heat resistance, rust resistance, acid resistance, and many other properties. One or several of these properties may be desired in a particular steel in order that a product into which the metal is shaped may function properly in service.

The physical properties of the ingot formed in the mold have an important bearing upon the mechanical operations to which the preliminary form will be subjected and, also, upon the physical characteristics and quality of the finished steel. Defects in the ingot will not be eliminated by mechanical working, such as rolling or forging, but will, instead, be retained by the product. If the ingot is sound, an important step has been taken toward good quality. On the other hand, if the ingot is not sound, some of the steel may be of inferior quality and lacking in dependability. A good ingot is absolutely essential to a high yield of good steel. A perfectly sound ingot may be defined as an ingot that is free from any cavity or opening, and that is composed of material which is the same throughout its entire length.

The size of ingots varies from 100 pounds to 20 tons. A common size used in the fabrication of steel weighs about 3 tons. The cross section of ingots is usually square or rectangular, with rounded cor-

Fig. 3. Ladling Molten Metal

Courtesy of Carnegie-Illinois Steel Corporation ners, or round. Ingots of the higher grades of carbon and alloyed steels frequently have corrugated surfaces. The size of the ingot, i.e., the cross-sectional area and the length vary and are determined by the following factors:

1. The product desired.
2. The type and capacity of the mills for hot working the ingot.
3. The nature or grade of steel.
4. The cost of rolling or hot working the ingot.

Common Defects in Steel Ingots. Some of the defects likely to be found in steel ingots are dendritic structure, pipes, blowholes, and segregation. Dendritic structure results from abnormal crystallization of the molten metal produced by the chilling effect of the cold, iron mold. Crystals begin to form on the ingot surfaces and grow in size toward the center of the ingot. This produces a tree-shaped (dendritic) grain structure which reduces the strength of the steel because of the weak planes embodied therein. In most cases, the chilling of the metal is localized at the surface of the ingot and does not extend inward—the result being that the center section of the ingot has a proper crystal orientation and tough structure. Fig. 4, which illustrates a cross section of a cast ingot of steel, shows the dendritic outer surface and the normal, free crystalline, inner structure. Note the cleavage planes at the corners and the central pipe.

Pipe is formed after the poured molten metal has solidified from the outside as a consequence of the chilling effect of the cold, iron mold. The body of solid metal is found to occupy less space than did the molten metal; hence a cavity or pipe is formed in the ingot as the result of shrinkage. Usually the pipe will be found in the upper center of the ingot—that portion of the mass which is last to freeze—as shown in Fig. 5. This figure illustrates steel ingots that are ready for testing.

Usually, the end of the ingot is cut away or cropped in order to eliminate the section containing the pipe. Changes in design of the mold may regulate cooling to such an extent that pipe will occur only at the top of the ingot where it can be eliminated by cropping.

Blowholes are caused by liberation of gases while the ingot is in the solid state. Some of these gases escape from the metal while it is in a molten state; others are trapped as the metal solidifies during the cooling period. Blowholes occurring near the surface of the metal may produce a serious defect in the ingot, while those occurring at or near the center (core) are of small consequence. When the ingots are hot-rolled, the blowholes near the surface will elongate and seams will appear in the finished steel.

Segregation is a condition produced by uneven concentration of elements contained in the alloy. It is accounted for by the fact that, in solidifying, those sections of molten metal which freeze first are purer than those which freeze last. Segregation in metals varies with the steel-production methods used. The molten metal first coming in contact with the chill surface of the mold freezes quickly and, in so doing, becomes relatively purer than the metal composing the inner portion of the pour, which freezes more slowly. Cutting off the upper part of the ingot not only will eliminate the pipe, but also will eliminate that portion of the ingot containing the highest degree of segregation (note ingot at far right in Fig. 5).

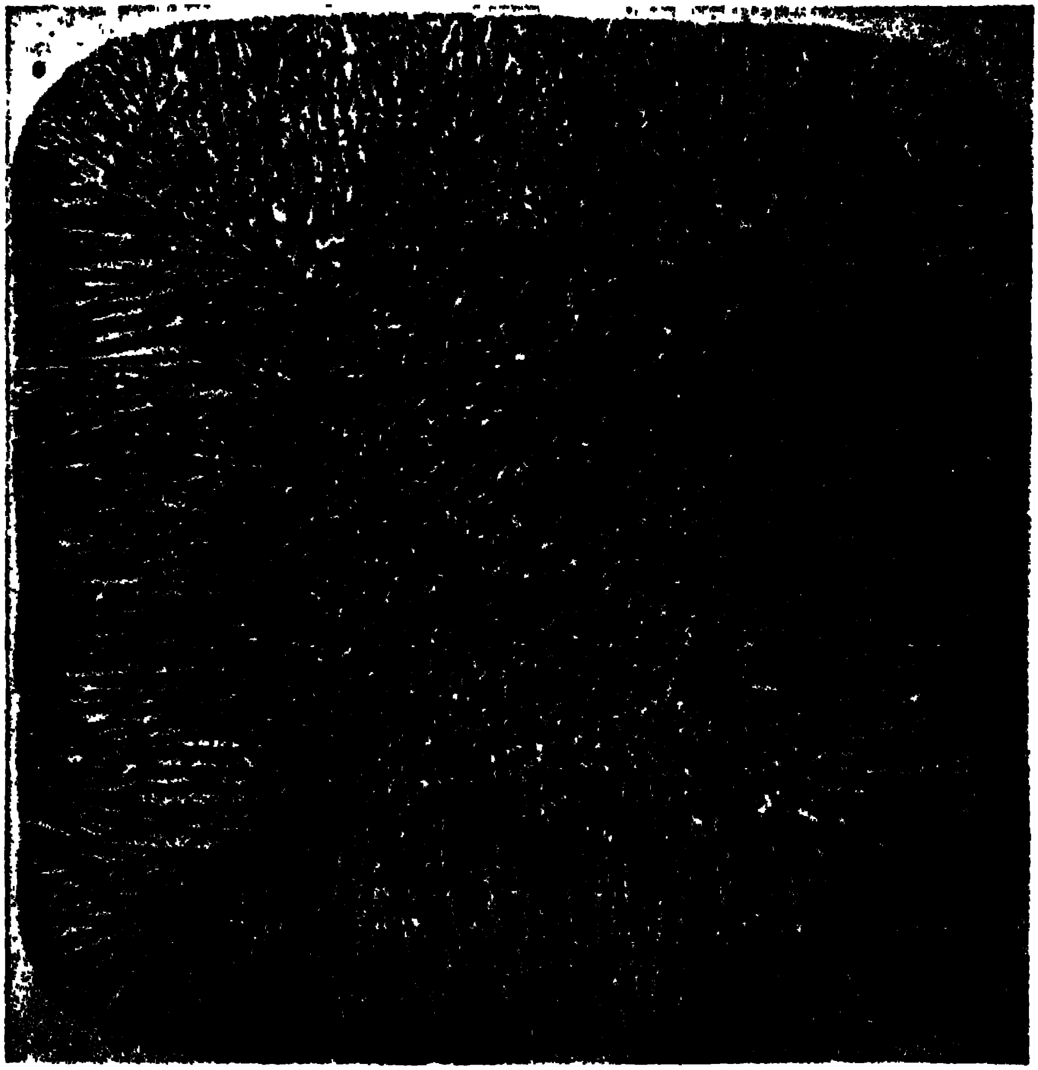


Fig. 4. Crystalline Inner Structure of Cast Ingot of Steel
Courtesy of Gathmann Engineering Company, Baltimore, Md.

A steel which does not tend to form gases during solidification will contain no blowholes. However, the chilling effect of the mold and the shrinkage of metal resulting therefrom will produce a central pipe in the ingot. In eradicating this, a *killed* steel is produced. Steel so designated is produced by a process applied in the manufacture of high-grade steels, such as special alloy steels and tool steels. Examples of steel which, though free of blowholes, contain central pipe, are the third and fourth ingots from the left in Fig. 5.

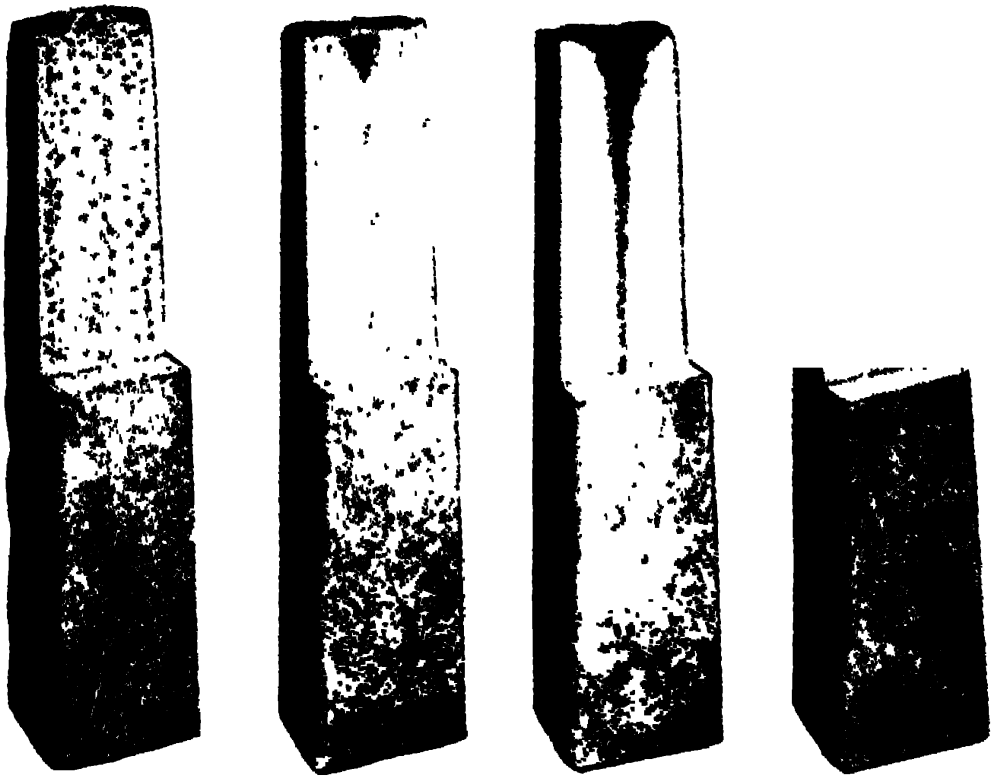


Fig. 5. Steel Ingots Ready for Testing

Courtesy of American Institute of Mining Engineers

Rimming steel (seen in the ingot at the far left in Fig. 5) is obtained when the steel is cast in such manner that the carbon and silicon are kept low, and little attempt is made to degasify the steel. Many blowholes are present in the specimen indicated, but there is a total absence of pipe, because the shrinkage which produces pipe is avoided by the formation of blowholes. It is recommended that the surface of the ingot be kept free of blowholes so far as is possible.

Steel of this kind provides the rolled sheets required for deep drawing and forming.

The second specimen from the left in Fig. 5, being partly degasified, is a medium between the killed and rimming steels, and is recommended for use in the production of structural steel plates, rails, and forgings.

Other defects which it is desirable to eradicate from the ingot are nonmetallic impurities or slag inclusions, scabs, and cracks. The ingot should also be free from internal stresses.

Steel-Making Processes. All kinds of steel, whether plain carbon or alloy, are produced in furnaces by remelting pig iron and steel scrap. Pig iron is the basic ingredient in the production of steel. It is a product of the blast furnace, where it is produced by a smelting process which results in the chemical reduction of iron ore to metal. There are different kinds of pig iron which are graded according to chemical analysis. It is, therefore, possible to select the most suitable kind of pig iron for a particular type of steel required in the design of a machine, engine, operating mechanism, or any product manufactured for useful service. There are, of course, a number of methods of producing steel. Economy of production and the required quality of steel for a particular need are factors that dictate the most suitable method to be used.

The three principal methods used in producing steel are named: open-hearth, electric-furnace, and Bessemer. The bulk of steel needed in industry is produced in open-hearth furnaces. Whichever method is used, the production of steel consists of reducing and refining the charge of pig iron and scrap by intense heat in a furnace. Various alloying elements are added in order to make whatever kind of steel is required to meet chemical and physical specifications.

In the open-hearth method, the charge is placed in the furnace, and intense heat is applied from above the material by the combustion of a mixture of air and gas. The generated heat oxidizes the impurities in the charge. These oxidized impurities separate from the molten metal because of their lower specific gravity and are drawn off in the form of slag from a suitable opening in the furnace. The refined steel is also drawn from the furnace in the molten state into a huge ladle, and from the ladle is poured into molds that will form ingots of various sizes—sizes that will be most workable in subsequent processing operations that the steel will undergo. Because of chemical variations in the iron ore, open-hearth steel may be produced either by the basic method or by the acid method. The basic method is most prevalently used. Fig. 6 shows a cross section of an open-hearth furnace fired with gas or liquid fuel.

High-grade steel is produced in electric furnaces because of the accurate control of metal composition and temperature that is possible in such furnaces. A mixed charge is placed in the furnace and the intense heat necessary for refining the metal is provided either by (1) carbon electrodes which enter the furnace and create an arc between themselves and the charge, or by (2) induction heating coils surrounding the container in the furnace holding the charge. Close regulation of temperature and control of atmosphere in the furnace to eliminate contamination of the molten metal are important factors in the production of refined steel. Samples for analysis may be taken during the melt as frequently as desired, which would indicate instantly whether an addition of alloys is required to suit exact physical and chemical specifications. This method makes it possible to produce steel of practically any desired purity and composition. Of course, electric-furnace methods are considerably more expensive than that of the open-hearth because of the high cost of electricity. They are recommended for the production of high-grade steels of

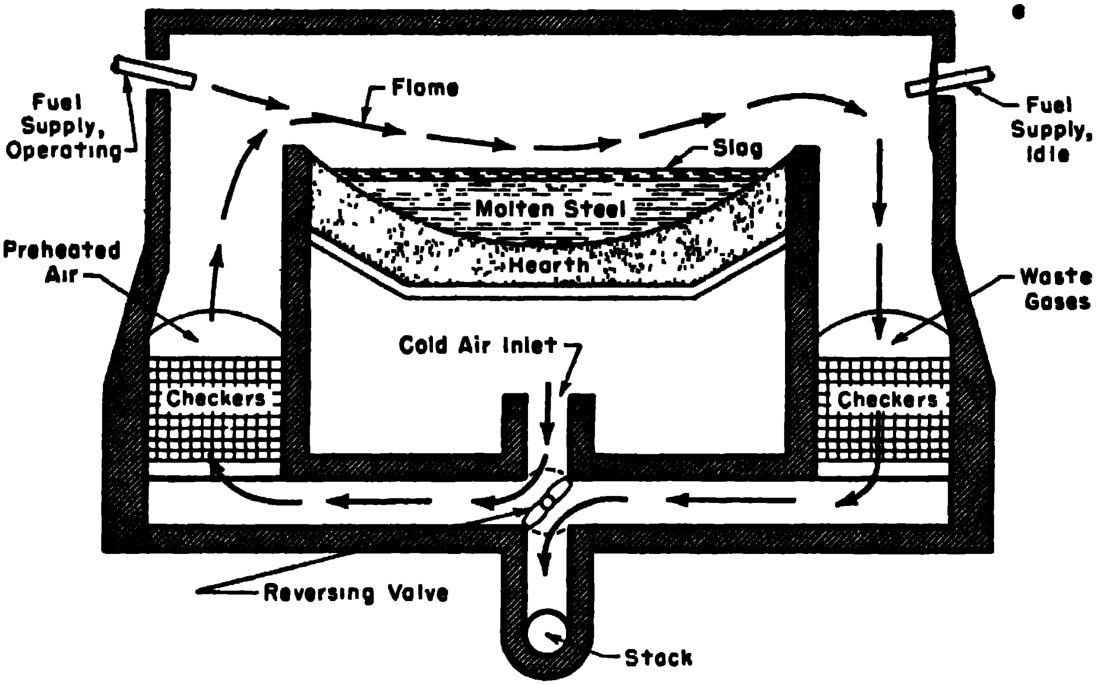


Fig. 6. Cross-Section Sketch of Open-Hearth Furnace Fired with Unregenerated Gas or Liquid Fuel

Courtesy of Steel Founders' Society of America selective quality, where the added expense is warranted. Fig. 7 shows a cross section of an electric-arc furnace equipped with three carbon electrodes which enter the furnace and carry the current to contact the metal charge.

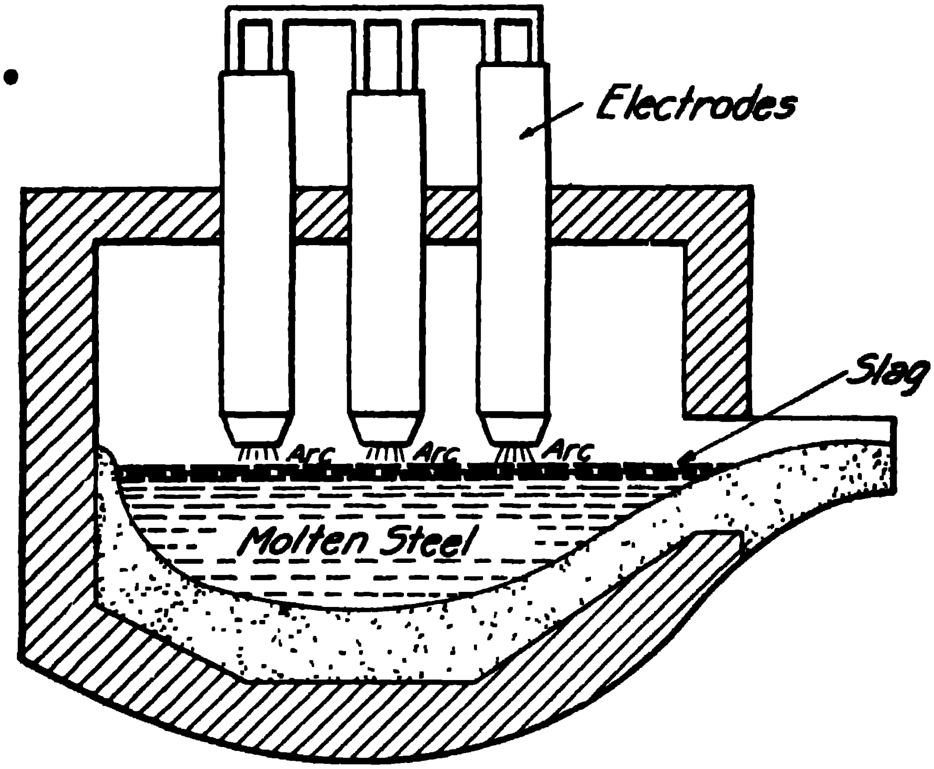


Fig. 7. Cross-Section Sketch of an Electric-Arc Furnace
Courtesy of Steel Founders' Society of America

Shown in Fig. 8 is a cross section of a high-frequency induction furnace. In this furnace, a high-frequency current is passed through a water-cooled copper tube constituting the primary coil of a transformer. A heavier, secondary current is induced in the charge constituting the secondary coil. The resistance of the metal charge will cause it to heat up to the desired temperature.

Today, the least amount of finished steel is produced directly by the Bessemer method, which is the oldest of the steel producing methods. However, it is employed as a preliminary

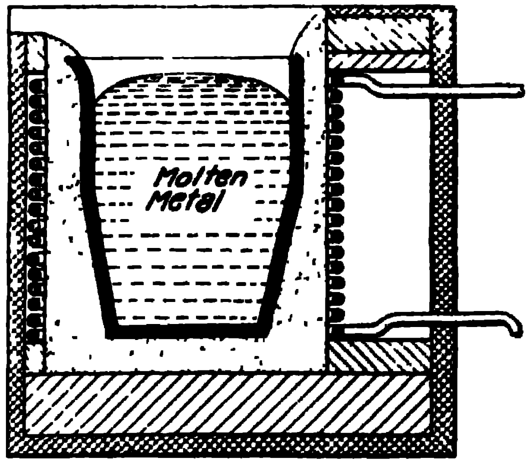


Fig. 8. Cross-Section Sketch of a High-Frequency Induction Furnace
Courtesy of Steel Founders' Society of America

method of melting steel, which is finally refined in the open-hearth furnace. This combination method, called *duplexing*, is used to a certain extent in present-day steel production. The advantage of the method lies in the fact that the excesses of silicon, manganese, and carbon in the charge are reduced rapidly in the Bessemer furnace by blowing an air blast through the molten metal, thus shortening the length of heating time required in the open-hearth furnace. A refined steel is produced by this combination method. In the direct Bessemer method, impurities in the metal charge are reduced to slag by the blast of cold air that is blown through it, the excess of carbon is burned out, and the molten steel is poured directly into a ladle and then into ingot molds. Fig. 9 shows the front view of a 1½-ton, side-blow converter in operation.

Fig. 9 Front View of 1½-Ton Side-Blow Converter in Operation

Courtesy of Steel Founders' Society of America

Classifications of Steel. Steel is one of the most useful metals known to mankind. Numerous products are manufactured from steel because of the great variety of useful properties this metal offers. Steel, because of its many varieties, may be classified according to (1) its chemical composition, (2) its structure, (3) its predominant physical properties, (4) the particular manufacturing process used in producing the metal, (5) its use in service, etc.

The following terms are commonly used to denote various commercial steels: kind, class, type, and grade. The term *kind* designates the process or method of manufacture. Examples of kinds of steel are: crucible, Bessemer, basic open-hearth, electric-furnace, and others. The term *class* refers to major divisions indicating size or use of steel. An example of a class of steel is: high-carbon, alloy, tool steel. The term *type* refers to certain qualities of steel, such as grain size or composition. An example of a type of steel is: fine-grain steel. The term *grade* is used to denote various divisions within different types of steel. These divisions are based on either the carbon or alloy content, or the physical properties of steel. An example of a grade of steel is: low-carbon, heat-resistant steel. The development of steel has reached such high level that there are in actual existence numerous variations in chemical and physical specifications. This makes it possible to obtain a suitable steel for practically any service condition. •

Improvement of Physical Properties of Metals by Mechanical Hot Working. As stated before, the steel ingot is formed by casting molten steel in a metal or refractory mold. The same procedure is followed with some modifications in producing other metal ingots. Because of the relatively slow cooling of the ingot, its crystalline structure is rather coarse and, therefore, mechanical hot working is necessary to refine its structure. Heat treatment is also useful in refining the coarse crystalline structure of the cast-steel ingot. The mechanical hot working of the metal consists, first, of heating it to a soft plastic state, and then working it by means of several methods—methods which will be described later in the text. Hot working of the metal rearranges the crystals of the cast ingot, and the metal flows in the direction of the working. The section of the metal is reduced; its grain structure is substantially refined. The suitability of the mechanical method employed is important. The metal may be worked through rolls, dies, or other devices.

The quality of the metal is greatly improved by mechanical hot working. The strength of the metal is substantially increased and, in some cases, even its hardness may be increased. The ductility of the metal, after it is hot worked, may be increased or decreased, depending upon the conditions which existed during the process.

Hot Rolling as a First Step in Hot Working of Metals. Rolling heated metals, steel in particular, is done for the purpose of converting the metal ingot into simple stock members from which definite parts may be formed, and for the purpose of improving the mechanical properties of the metal. Rolling transforms the structure of the cast-steel ingot into a body of refined grain, and the steel becomes more ductile and also stronger and tougher. Furthermore, the steel's resistance to suddenly applied shock loads is greatly increased after the application of the rolling process. Rolling is an economical method of producing large quantities of simple steel shapes, such as structural forms, rails, sheets, plates, and the intermediate shapes required for forging, wire drawing, etc.

Before being rolled, the cast ingot is placed in a soaking pit, where its temperature is raised so that it is satisfactory for hot working of the metal. Fig. 10 shows how molds are stripped from the steel ingots. Fig. 11 shows the removal of the heated ingot from the soaking pit.

Fig. 10. Stripping Molds from Ingots

Courtesy of Carnegie Illinois Steel Corporation

The process of rolling' consists of passing the hot ingot between two rolls rotating in opposite directions at a uniform peripheral speed. The space separating the rolls is adjusted so that it is less than the thickness of the ingot passing through. In this way the cross section of the ingot is reduced and its length is increased, resulting in the three fundamental forms necessary for further processing—blooms, billets, and slabs. Fig. 12 shows a two-row, 35-inch, blooming mill with a bloom (or ingot) between the rolls.

Rolling Mills and Equipment. Rolls, which are the essential tools used in rolling metal, are mostly made from high-quality steel. High-grade, cast-iron rolls may also be employed to a limited extent, especially where the rolling pressures are not too excessive. A roll consists of three essential parts, a barrel-shaped *body*, a *neck*, and a *wobbler*. The rolling is done on the body, the shape of which varies in accordance with the type of rolling desired. It may be smooth and straight for flat rolling, or it may be grooved if its purpose is to roll definite shapes, such as structural members and rails.

The roll diameters vary from a few inches to five feet, and the amount of reduction of the cross-sectional area of the ingot or bloom is governed by the size and weight of the roll. For the sake of economy, working rolls may be of small diameter backed up by inexpensive, heavy, idling rolls that prevent bending under pressure.

The neck is the portion on which the roll rotates in the bearing. The wobbler is a star-shaped coupling through which the roll is driven by means of a hollow cylinder that connects this portion of the roll to the driving shaft. This arrangement makes the drive a flexible one and, in case of excessive load or other unusual condition, breakage will occur in the relatively inexpensive coupling and not in the roll itself.

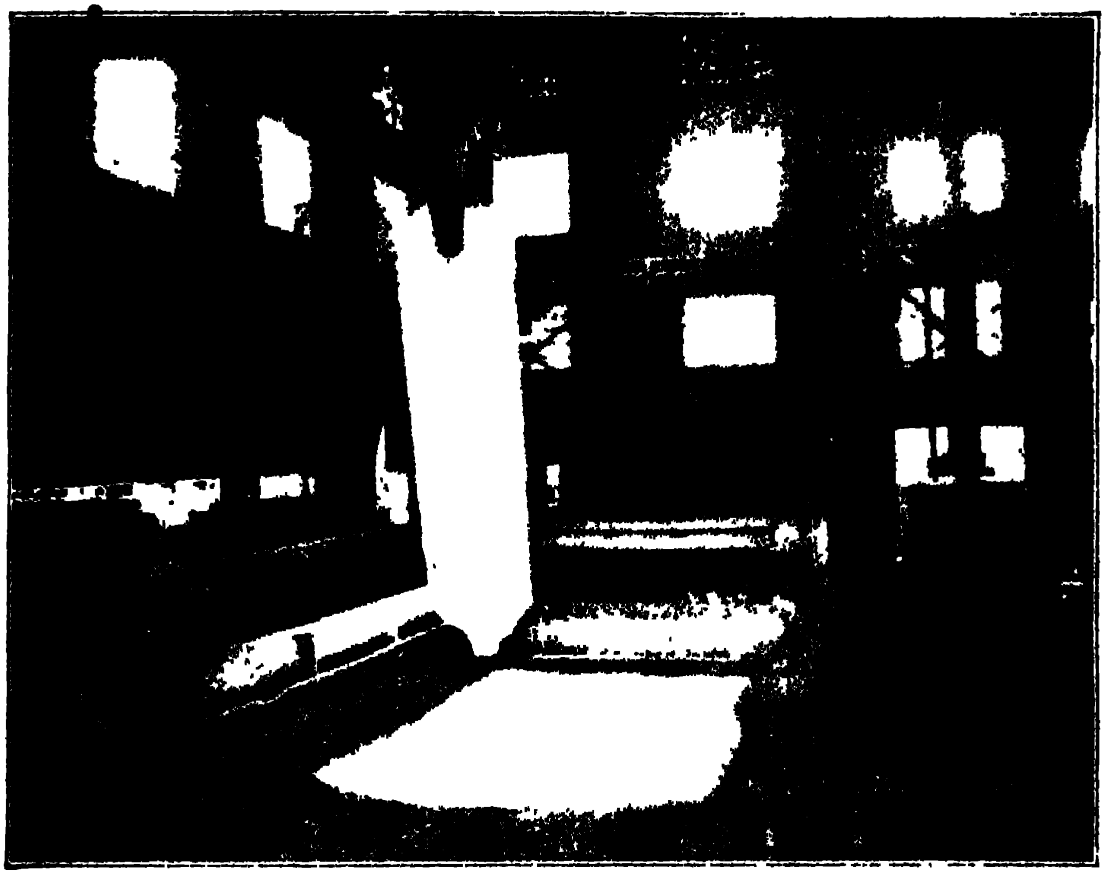


Fig. 11. Removing Ingot Heated to Proper Rolling Temperature from Soaking Pit

Courtesy of Bethlehem Steel Company, Bethlehem, Pa.

Rolling-mill *stands* are classified according to the arrangement of the rolls in their housing. A two-high stand consists of two rolls; a three-high stand consists of three rolls; a four-high stand consists of four rolls. In a two-high mill, the rolls rotate in opposite directions. In a two-high reversing mill, rotation of the rolls is reversible in order that the cross section of the ingot may be continuously reduced by back-and-forth passes between the rolls until a desired size is obtained. Fig. 13 shows a three-high stand—the top and bottom rolls rotate in the same direction and the middle roll rotates in the

Fig. 12. View of 35-Inch Blooming Mill

Courtesy of Bethlehem Steel Company, Bethlehem, Pa.

opposite direction. Tables having a height-adjustment feature may be arranged, with reference to the mill, in such a way that it is possible to pass the ingots or blooms between the upper or lower pairs of rolls.

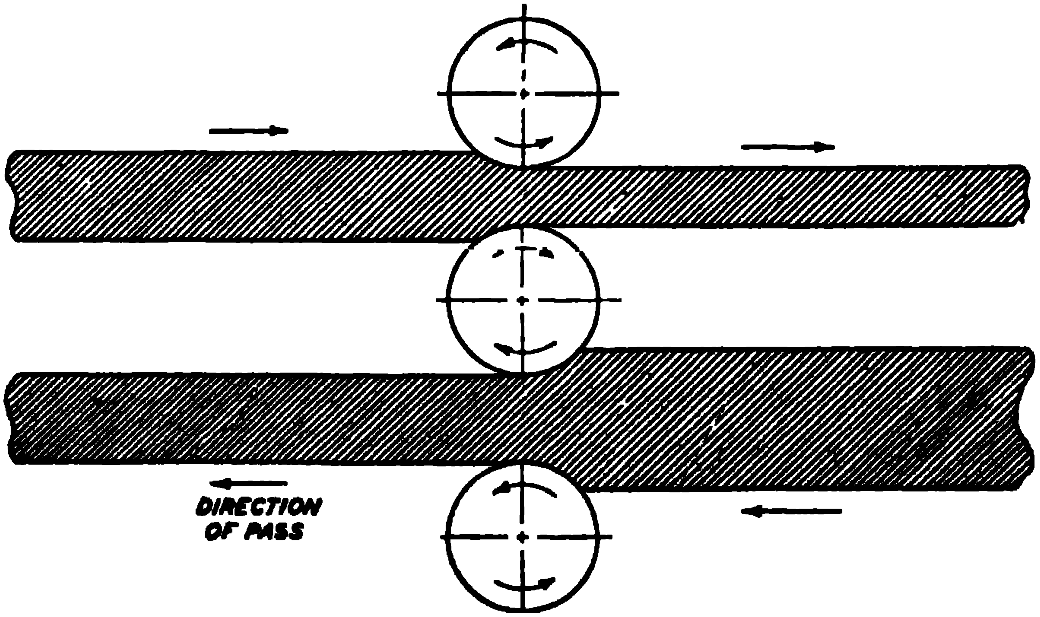


Fig. 13. Principle of the Three-High Rolling Mill

A continuous mill is a two-high mill consisting of a number of stands arranged one after another in such a way that the material can be passed through each stand successively. The rolls of each successive stand are driven at an increased speed to accommodate the increasing length of the material. This arrangement is suitable for large and rapid production of rolled steel, since the material passes continuously from one stand to the next until it reaches the final pass. Rolling speeds may be increased considerably—frequently, the material in a modern mill can be made to move at a speed of 4,000 feet a minute. Sections of complex shape cannot be produced on a continuous mill. The initial cost of equipment for a continuous rolling mill is high, but the expenditure is warranted considering the savings in labor and the production achieved. Fig. 14 shows a continuous rolling mill in operation.

Fig. 14. Continuous Mill for Rolling Billets
Courtesy of Carnegie-Illinois Steel Corporation

The proportioning of the surface speeds of the various sets of rolls is arranged by means of a system of driving gears. Compensation for wear of the rolls and provision for rolling various thicknesses of metal are made possible by making the rolls adjustable. Feeding of the material into the rolls is done by means of properly designed guides and rolling tables.

The rolling of the steel is done while it is in the plastic state, except when sheets are rolled out on the finishing passes. Nonferrous metals such as brass, aluminum, and nickel-silver are usually rolled cold in a series of operations. Intermediate annealing is necessary to soften the material, which becomes hard as a result of cold working A great deal of copper is hot rolled into rods, from which wire is made.

The steel ingots for structural shapes, rails, and plates usually weigh from 3 to 20 tons, and are of square cross section with rounded corners. These are converted into blooms, billets, and slabs which are reheated and rolled, or formed by other methods, into their final shape. Reheating of the ingot, after it has been stripped from its mold, occurs in soaking pits as previously stated. The fuel for the soaking pits is usually gas. Where the mill is located near the blast furnace, waste gases from the furnace supply the heat for the soaking pit. The temperature of the pit ranges from 2000° to 2300° F. The length of time that an ingot is kept in the soaking pit depends on how much the ingot has been allowed to cool. During the soaking time, the temperature of the ingot becomes equalized throughout, as is necessary for successful hot rolling or for any other method of hot forming.

Hot Rolling of Billets and Bars for Forgings. When hot rolling billets and bars for forgings, it is frequently necessary to use special rolling equipment in the mill in order to obtain extra passes of the hot-worked metal. This particularly applies to steel where closely controlled finishing and desired physical properties of the hot-worked metal are required. The billets and bars thus produced are free from pipe, excessive segregation of impurities, and injurious surface defects. They are now ready to be converted into finished products by means of various forging methods, followed by final machining and grinding.

Where high-grade-steel, forged products are required, the preliminary billets and bars are often rerolled, thus eliminating any possible defects remaining in the steel. The surface and the interior of the metal are assured soundness, and the maximum, potential, physical properties of the steel are developed by the additional hot working. Fig. 15 shows a diagram illustrating the number of passes and sequence of operations necessary to reduce the cross section of a 4″ x 4″ billet to round bar stock. The number of steps varies with the shape and size of bar wanted. These steps that are followed in rolling a square, steel billet to a round bar result in a further compacting of the metal and development of the flow lines in the direction of the working.

The Advantages of Forging Metals. The most important advantage of working a metal by any of the commonly practiced forging methods is the substantial improvement effected in the metal itself. Forging a metal into a required product is more than a means of imparting the necessary shape to a piece of metal. The working of the metal into shape by means of modern forging methods also refines the grain structure of the metal, develops its inherent strength-giving characteristics, improves its physical properties, and produces a structural uniformity free from hidden internal defects. The strength and toughness of a forged metal assures a greater factor of safety whenever the forged products are subjected to excessive loads and to the internal stresses resulting from these loads in actual service. The additional margin of safety is highly desirable, especially in the case of unforeseen emergency which may occur when the product, such as a part of a motor, engine, or an operating mechanism, is subjected to sudden stresses which were unknown when the designer computed the normal stresses in the required part.

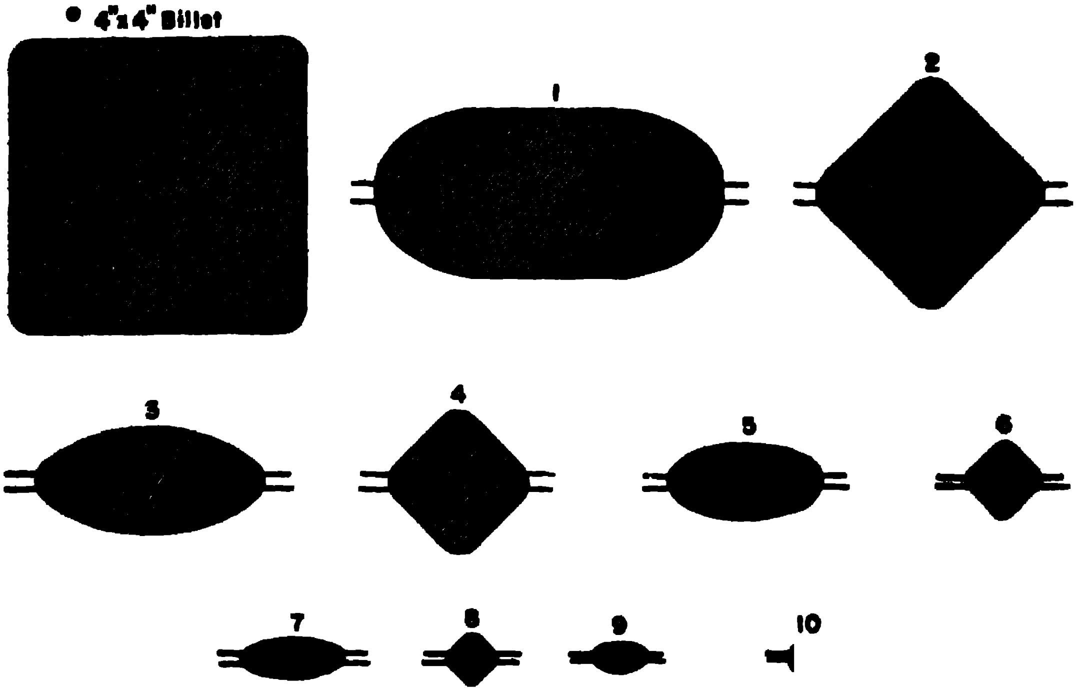


Fig. 15. Diagram Illustrating Number of Passes (10) and Sequence in Reducing the Cross Section of a 4" x 4" Billet to Round Bar Stock

Courtesy of Carnegie-Illinois Steel Corporation

The direction and concentration of the fiber-like grain structure of forged metal, especially at points where it is assumed that possible stresses will be greatest, are controlled by any of the selected forging methods. Forging also develops a maximum combination of desirable physical properties in the forged part—properties capable of withstanding safely the effects of specific service requirements. Modern techniques in the development of a wide variety of metal alloys make it possible to select the best suited metal for a required product. Such a selection, together with use of a proper forging method and suitable heat treatment, will result in the production of a metal object that can meet rigid specifications.

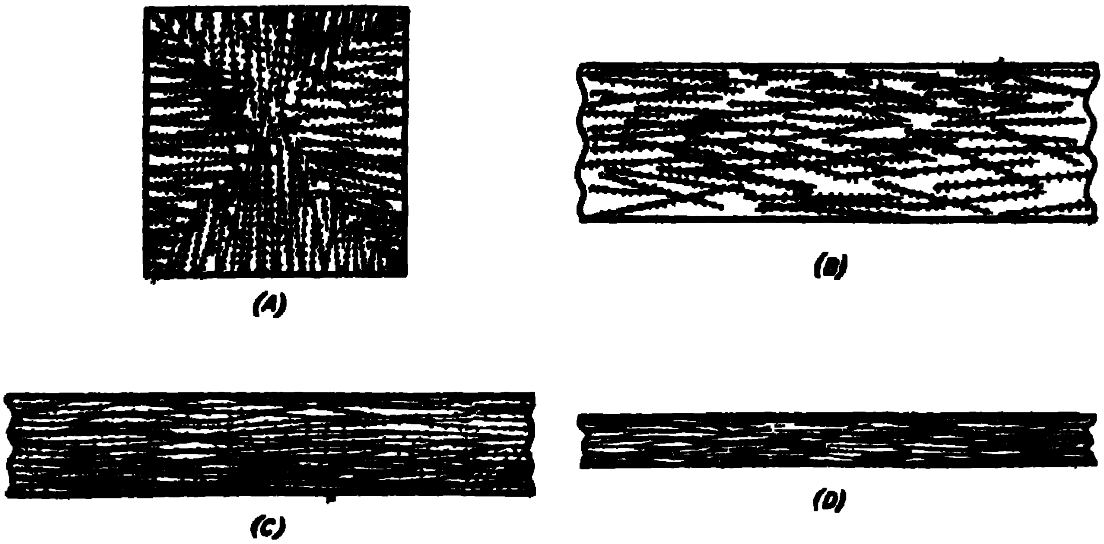


Fig. 16. Development of Flow or Fiber by Working

When a part is being forged, the particles of metal of different analyses are elongated into long fibers, which are known as flow lines. Fig. 16 illustrates the development of flow or fiber by forging. *A* shows the dendritic segregation in the cast ingot section. If this condition is present, a hot-acid etch will clearly show it. *B* shows the effect of only a limited amount of forging, or other hot working, which causes a distortion of the dendritic segregation in the direction of the metal flow. C illustrates the effect of increased forging or other hot working. A definite reduction of the metal may be seen in the diagram. Finally, *D* shows how the original dendritic structure has been developed into flow lines or fiber.

During the period when the metal is hot worked, more or less diffusion is taking place, which causes the segregation present in the cast ingot to diminish and finally disappear. The result of increased hot working is an approach to a homogeneous steel having a finer flow or fiber. Fig. 17 shows how the condition of flow lines can be developed in any forging by sectioning the forging and subjecting it to the attack of a boiling solution of 50 per cent hydrochloric acid and 50 per cent water. A hot-acid-etched section of a drop-forged crankshaft is illustrated.

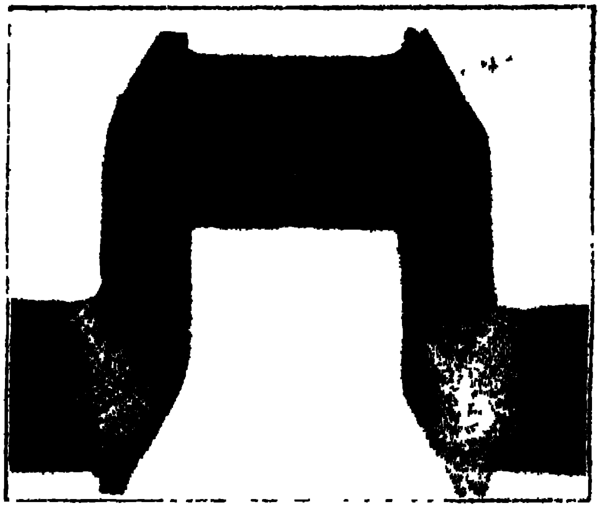


Fig 17. Hot-Acid-Etched Section of a Drop-Forged Crankshaft

The effect of these flow lines is to produce marked directional properties in steel. Metal forgings with marked fiber have much less ductility and toughness when tested across the fiber than when tested in the direction of the fiber, behaving in a manner similar to wood. Fig. 18 shows how flow lines are used to advantage in forging typical parts, such as a gear blank, a hook, and a crankshaft. *A* shows the development of the flow lines in a bar through forging or rolling. *B* shows how upsetting this bar produces a gear blank which has flow lines concentrated where they will give greatest strength to the teeth. The progressive development of a hook is shown in *C*, *D*, *E*, and *F*, where the greatest advantage of flow lines is obtained. The bend in the hook is the most important

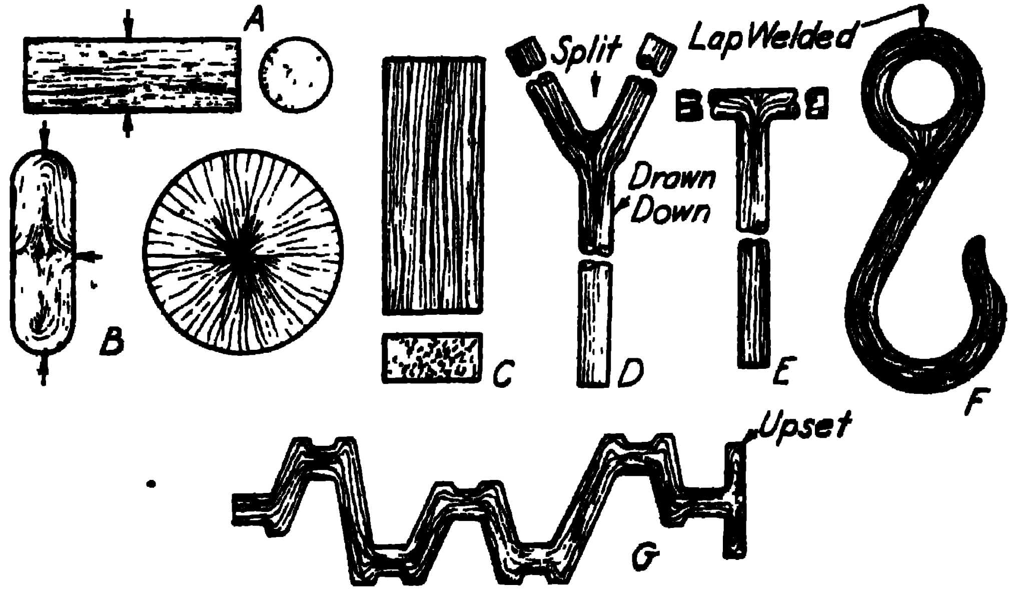


Fig. 18. How Flow Lines Are Used to Advantage in Forging a Gear Block, a Hook, and a Crankshaft

area of the structure, since the greatest concentration of stresses will develop there when the finished hook is used in service. G shows the flow lines, or fiber, in a forged crankshaft—lines which follow the general contour of the product.

Another advantage of forging a product lies in the fact that substantial savings in weight are obtained without sacrificing strength or safety. Thinner metal sections may be used without reducing the maximum strength of the product, thus saving valuable space which is so essential in an assembly of a modern machine, engine, or an operating mechanism. Forging a component part of an assembly will develop in the worked metal a maximum resistance to tensional, compressive and torsional stresses, and to fatigue. Such improvement in the metal results from the controlled grain flow that occurs at the time of forging. Of course, in order to achieve the best results in the manufactured part, the proper metal and production method must be selected.

Modern forging methods make it quite possible to produce forgings with close tolerances. Such forgings require considerably less machining than forgings produced by primitive methods. The wide variety of metals available, and their alloys, enable the producer of forgings to select metals that are machinable without difficulty—a circumstance that results in reduced machining and tool costs.

REVIEW QUESTIONS

1. What is a common practice in judging the general quality of a metal?
2. What is real metal quality as respects a product designed to satisfy specific service conditions?
3. Explain the meaning of a balanced combination of physical properties of a metal selected for a product.
4. Define the physical property of toughness in an engineering material.
5. What is the first industrial form of most metals?
6. What are the normal constituents of common carbon steels?
7. Name some other constituents that may be present in special alloy steels.
8. What is the size variation of steel ingots?
9. Name, describe, and briefly explain the cause of some common defects in steel ingots.
10. What are the three essential methods used in producing steel?
11. Name the five principal classifications of steel.
12. Describe briefly the hot-rolling method of shaping metals.

13. Describe the essential tools, known as rolls, which are used in rolling steel.
14. What is a continuous mill as used in rolling steel?
15. What is the purpose and temperature of a soaking pit?
16. Describe the shaping of billets and bars preparatory to forging.
17. State the most important advantages of forging metals.

CHAPTER III

Hand Forging

Early Blacksmithing. The mass-production methods used in modern forging industry are of very recent origin. New methods and improvements in existing methods are being continuously developed to improve the product and increase production. The forging industry seeks to reduce the cost of the product without sacrificing its quality. Previous to the advent of modern techniques, hand forging was the chief method used in hammering heated metals into desired shapes. The hammering operations were mostly manual and carried out by blacksmiths, who made from iron and steel all the shapes that were required and could be plastically formed by hand methods. Of course, at the present time, the cost of hand forging and the inaccuracies of the method make hand forging of metal well-nigh prohibitive; it is, therefore, restricted in extent and used in a limited way to produce a few simple shapes in maintenance work, railroad repair-shop operations, product design, and similar applications. However, in most shops, hand forging gradually has been abandoned and the work is performed by power-operated hammers instead. Inevitably, the old forges used for heating metals yielded place to modern furnaces.

The principles of hand forging still apply to modern machine-forging processes, however. Many forged products, when they are in the design stage, are frequently developed by hand forging before reaching their final stage of approved design. This method is certainly less expensive than making costly dies for products in their initial stages of development. It is strongly recommended that a careful study of hand-forging equipment and methods should serve as a background for the analysis of the more complex machine-forging methods and tools used in modern mass production.

Hand Tools. As stated before, hand forging is still practiced, although to a limited degree, in the shaping of small and light parts and occasional tools, which may be needed in shop maintenance and repair work. Small mechanical hammers are often used instead of manual hammers; also, a number of small tools are adapted to increase the speed and accuracy of the operation. These tools usually have wooden handles and are held in the hand while being struck with either sledge or mechanical hammers. Fig. 1 shows a group of commonly used hand-forging tools. *A* illustrates the common ball-peen hammer, which is best suited to practically all of the hand-

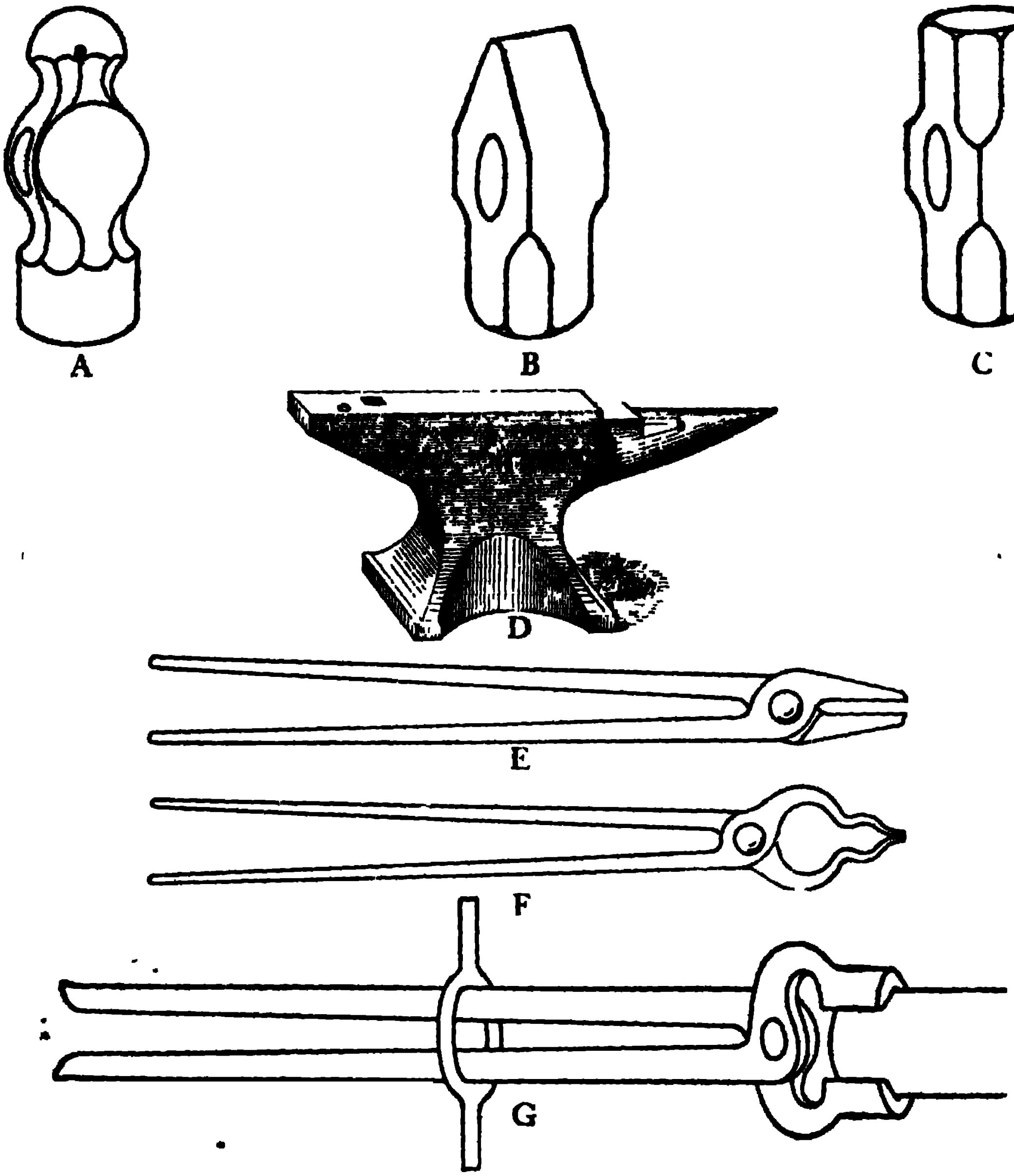


Fig. 1. Common Hand-Forging Tools

forging operations. *B* shows the cross-peen sledge, and *C* shows the double-faced sledge. The sledges are the heavier hammers used by the hand forger's helper, and they vary in weight from 5 to 20 pounds. *D* shows the blacksmith's anvil, an implement that has been used in practically the same shape and form for many centuries. Occasionally, anvils of special shapes are designed and may be used for hand-forging operations, but their application is fundamentally the same as that of the common-type anvil, which can be adapted to practically any hand-forging operation. The anvil shown at *D* consists of a body *a* usually made from wrought iron to which a hardened steel top or face is welded. The portion which is designated *b* at the right is the horn, and the portion at the left designated *c* is the tail of the anvil. The base and feet upon which the anvil rests are at the bottom. There are two holes at the tail portion of the anvil. One is square and is called the *hardie hole;* the other is round and is called the *spud hole.*

Tongs of various shapes are very useful in hand-forging operations. Frequently parts to be hammered on the anvil cannot be held with the hands, but with the aid of suitable tongs these parts may be very conveniently manipulated. Small work, such as wires, and large work, such as ingots and bars, can be handled by properly designed tongs to suit each case. The jaws of the tongs are designed to grasp the parts to be handled and hammered on the anvil. A variety of tongs commonly used in hand forging is shown in Fig. 1. At *E*, flat-jawed tongs are shown; *F* shows pick-up tongs; *G* illustrates the link for clamping tongs on heavy work. These are only a few of the common-type tongs. There are numerous other tongs designed for the purpose of meeting whatever requirements may arise when forging needed parts and tools of assorted weights and shapes.

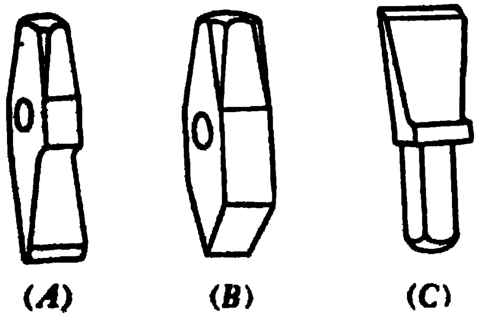


Fig. 2. Chisels

Other hand tools include various *chisels* which are used to cut off hot stele or to notch cold steel. Fig. 2 shows a set of chisels which are used for cutting off steel: *A* is the hot chisel, *B* is the cold chisel, and *C* is the hardie. The hardie is used by placing it in the square hole in the heel of the anvil, and striking the steel with the face of a hammer while resting the steel in contact with the cutting edge of the hardie. *Swages* of various forms are used for forming and finishing convex surfaces, round holes, and other shapes. Fig. 3 shows a set of swaging tools designed to shape round work. The upper tool is known as the top swage and is provided with a handle similar to a hammer handle. This tool applies the force upon the heated metal which is held on the lower swaging tool. This lower tool, known as the bottom swage, is held in place by a square stem or shank which extends downward and fits into the hardie hole in the tail of the anvil (shown in Fig. 1). Tools having hardie-hole stems should never be used on an anvil if they are so tight-fitting that it is necessary to drive them into place. *Fullers* are tools used for forming grooves or hollows while hot metals are being hammered into required shapes. Fig. 4 shows a set of fullering tools designed for working grooves or hollows into shape. A set consists of a top tool and a bottom tool. The top tool is provided with a handle and is used for finishing metal at round corners, around bosses, and on the inside of angles. The bottom tool has a square shank, which fits into the square hole of the anvil. Use fuller to spread metal in one direction only.

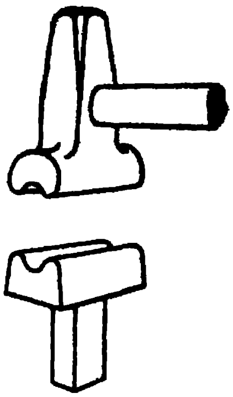


Fig. 3. Swages for Round Work

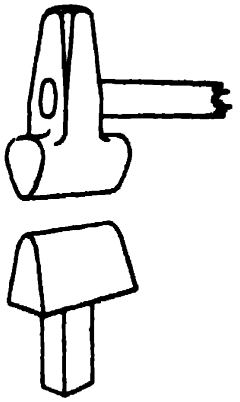


Fig. 4. Fullers

Various tools are designed for smoothing off flat work in the finishing process. These tools are known as *set hammers* and *flatters.* The set hammers are useful for working hot metal and forcing it into corners and narrow places. The flatters are designed for working wide, flat surfaces. *Round punches* are employed for punching round holes in hot steel. Appropriate punches of other various shapes are used for punching holes of oval outline, square outline, etc. Fig. 5 shows a set hammer. Fig. 6 shows a flatter. Fig. 7 shows a round punch.

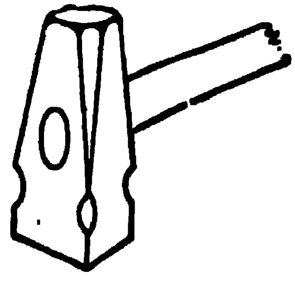


Fig. 5. Set Hammer

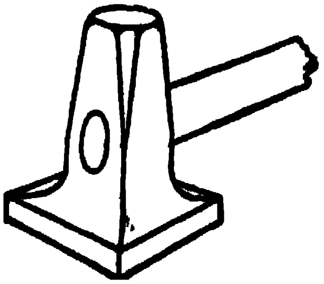


Fig. 6. Flatter

The Blacksmith's Forge. The simplest forge or furnace used by the blacksmith is an open hearth with forced draft. In it iron, steel,

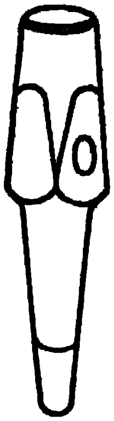


Fig. 7. Round Punch

or other metals can be heated and made ready for hammering into desired shapes. Refractory material, such as firebrick, is commonly used to build this type of forge, which is usually of rectangular shape. A simple hood is provided at the top of the forge to catch smoke and convey it into the smokestack. A water tank made of iron is often fastened to the side of the forge; this tank is chiefly used by the blacksmith for quenching a heated, steel tool in order to harden it. The blast (forced air) for these forges may be supplied by blowers or by hand power. An opening (tuyere) is arranged at the bottom of the forge, and this opening admits air under the fire; it can be regulated by a suitable valve arrangement.

Blacksmith's forges are made in numerous shapes and sizes, but all of them are built according to the same principles of construction—principles which are based on the fundamental purpose of a forge to contain the fire necessary for heating metal before hammering. A deep bed of coke should be maintained with a minimum amount of blast, via the tuyere, during the heating of steels in a blacksmith forge. A shallow bed of coke with a maximum amount of blast may be responsible for excessive oxidation (formation of scale) and possible burning (melting and sparkling) of the steel while it is being heated.

Fig. 8 shows a down-draft forge provided with a hood for carrying off smoke. A pipe is connected to the hood and extends downward, as shown at the left in the illustration, to an underground flue, which leads to an exhaust fan which draws out the air. This arrangement of underground piping is known as a down-draft system. The pipe furnishing the blast of air is also located underground; at the right in the illustration, a small pipe may be seen which connects with the underground blast pipe and leads upward to the tuyere. A simple valve arrangement, controlled by a handle, regulates the amount of blast admitted to the fire.

The air blast in some of the older-type forges is produced by bellows, whereas the more modern-type forges employ rotary fans, also known as centrifugal blowers, which may be hand-driven for small forges, or power-driven for most forges. When power-driven, the fans or blowers are operated by a belt from a pulley on the line shaft, or by a belt from an electric motor, or by a motor directly connected to the blower. The predominant fuel used in the blacksmith's forge for heating wrought iron and steel is a good quality of soft coal, free from sulphur, which is broken up into small lumps for best results. Coke is also a desirable fuel for heating iron and steel, because it does not tend to choke the fire in the forge. Charcoal is an excellent fuel, since it is free from sulphur and other undesirable impurities and gives a clean fire. Charcoal is especially recommended for heating carbon steels, but not for high-speed steels, because the temperatures developed from burning charcoal are not sufficiently high to properly heat the latter-type steels. Gas, oil, and powdered coal are also used as suitable fuels in the blacksmith forge for heating both iron and steel.

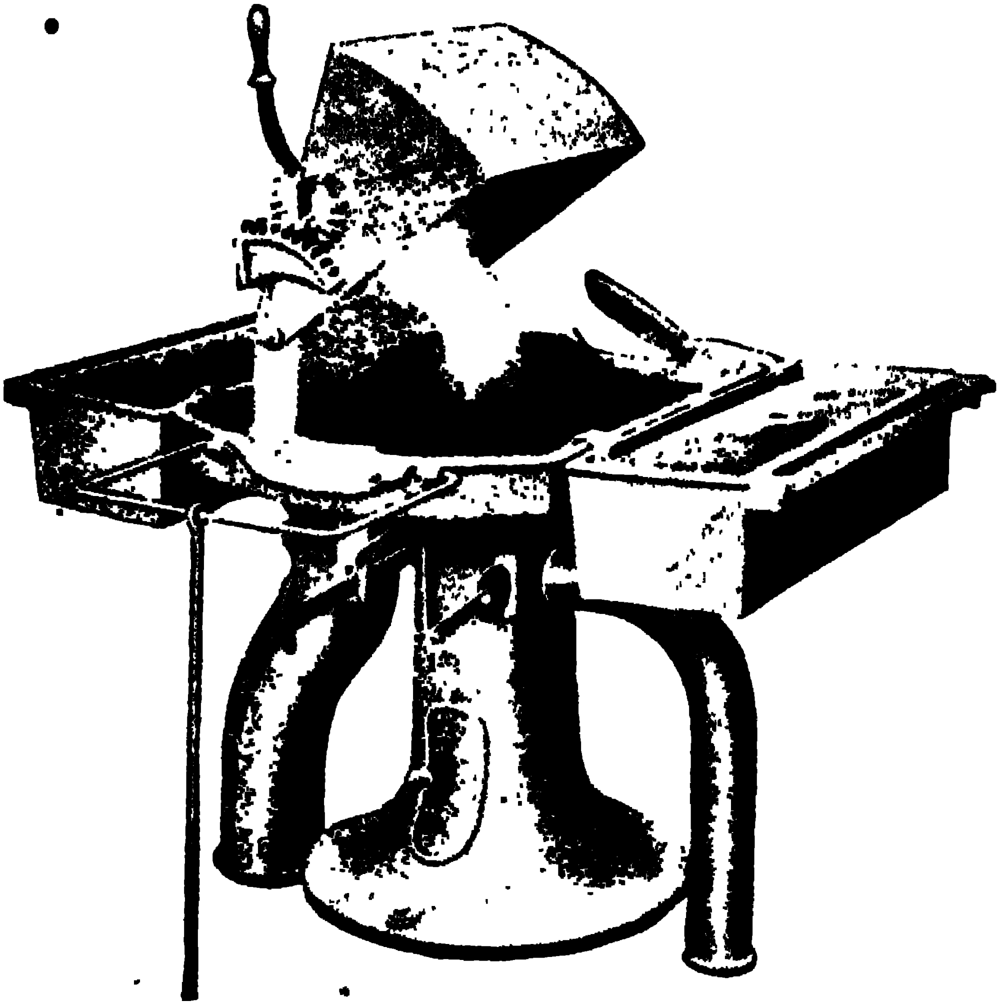


Fig. 8. Down-Draft Forge

Courtesy of Buffalo Forge Company, Buffalo, N Y.

Heating for Forging. The heating of a metal is one of the most important operations in the production of a forging. Frequently, this operation receives little attention, with the result that numerous difficulties are often encountered during the forging operation and during the heat treatments which usually follow forging. Many of the defects which seriously affect the behavior of the finished, forged piece are caused by improper heating of the metal prior to forging. Among the errors made in the heating of metal, *overheating* and *nonuniform heating* are the most prevalent.

The proper rate of heating the metal is such that no great difference in temperatures occurs between the surface and the center of the metal. When a metal whose surface is much hotter than its center is worked, a nonuniform effect of metal flow may result in internal bursting of the forging. Accepted forging practice specifies approximately one or two hours per inch of section of a piece of metal, as a proper rate of heating. The time of soaking (equalizing the temperature) the metal at the maximum temperature should be long enough to insure uniform temperature throughout. A small steel bar may take only thirty minutes to be brought up to forging temperature and then only ten to fifteen minutes for soaking before forging. A very large steel ingot may take over eighty hours for heating and thirty hours for soaking.

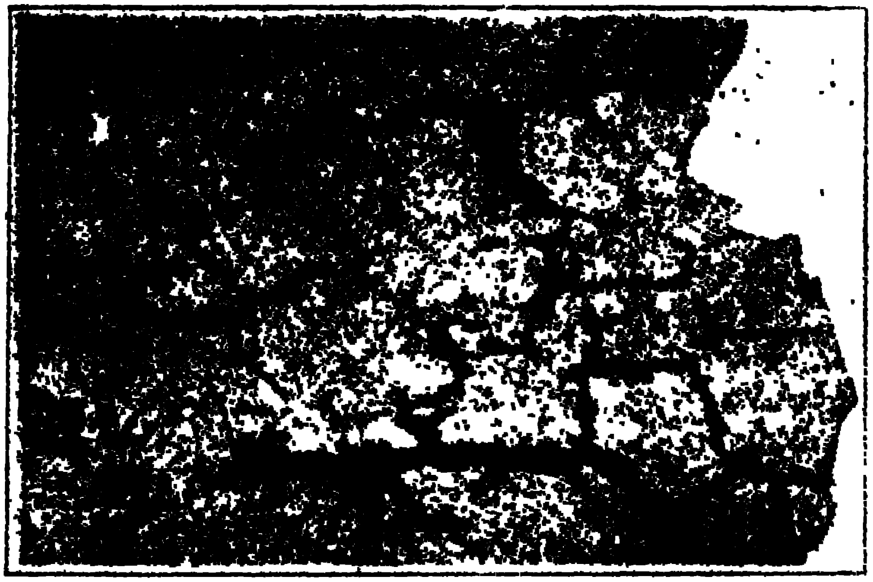


Fig. 9. Surface of a Section of a Burned Billet Overheated in Forging
Courtesy of American Society for Metals

Forging Temperatures. Because of the ease of forging at high temperatures, there is a tendency to heat the work to much higher temperatures than those actually required for satisfactory forging.

Excessive temperatures may result in burning, which destroys the cohesion of the metal, as shown in Fig. 9. Remelting the metal is the only thing left to do when it is overheated and burnt. If the metal is heated to an excessive temperature but is not burnt, the high heating temperature will result in a high finishing temperature and coarse grain structure. The composition of the metal determines the beginning of burning and melting temperature ranges; the heating of the metal should stop short of these temperature ranges by at least 200° F. The amount of hot forging to be done will determine how close to the burning temperature the metal should be heated. If considerable changing in shape is required to bring the raw material into finished form, the metal is heated to the limit short of burning or melting it. However, if only a slight amount of forging is necessary to form the metal, it should be heated just high enough, within the hot working range, to accomplish the finishing at the proper finishing temperature.

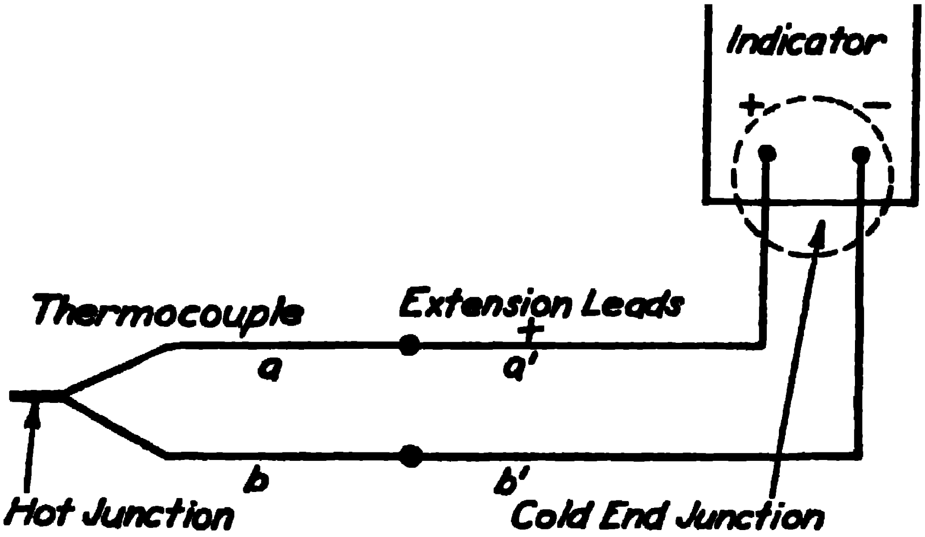


Fig. 10. Diagram of a Thermoelectric Circuit for Indicating Furnace Temperature

Measuring Temperatures. Numerous modern devices have been developed for measuring temperatures in furnaces where metal is heated preparatory to forging. A thermoelectric pyrometer system is most generally used for measuring the temperature of a furnace. The system consists of a thermocouple at the furnace, and a temperature measuring instrument that is connected to the thermocouple by wires. The measuring instrument may be the indicating type or the recording type or, in some cases, an instrument incorporating both features. Fig. 10 shows a diagram of a pyrometer circuit.

The thermocouple shown in Fig. 10 is a simple device made of two wires of different composition, which are welded together at one end and connected to the indicator at the other end. The welded end is placed in the furnace and forms the *hot junction*. The wires connected to the indicating instrument form the *cold junction*. The mere insertion of the hot end of the thermocouple in the furnace does not give a true temperature reading of the steel being heated in the furnace. Sufficient time must be allowed for the steel to heat up to the temperature of the furnace, and for the thermocouple hot-end junction to do the same, in order to obtain an instrument reading representing the true condition of the heated metal.

There are other satisfactory commercial types of pyrometers and temperature indicators. No matter what type of instruments are used, they should be frequently checked (about twice a week), if they are used continuously. Failure to periodically check the instruments may cause serious defects to become present in finished products.

There are some simple methods which have been used for many years to determine the temperature of heated metals, particularly iron and steel. These methods demand a trained eye to tell approximately the temperature of the metal under consideration. Of course, there is a possibility of error in a visual method of temperature identification, since no one can accurately determine the temperature of a heated metal by its color. Table I gives some idea of the color that metal is expected to be at different temperatures. A blacksmith hand forging a product has only one practical method of determining the temperature of the iron or steel heated in the coals of his fire—observation of the color of the metal. For exact forging temperatures of commonly used carbon and alloy steels, the student is referred to the *Forging Handbook*, published by The American Society for Metals of Cleveland, Ohio, 1939. The Aluminum Company of America and Reynolds Metals Company publish pamphlets in which detailed information is given regarding the exact forging temperatures of various aluminum alloys. For forging temperatures of other nonferrous alloys, the student is referred to pamphlets published by Revere Copper and Brass Incorporated, American Brass Company, and Dow Chemical Company. For detailed information regarding all properties of metals, the student is referred to the *Metals Handbooks*, published by the American Society for Metals of Cleveland, Ohio, 1948.

TABLE I. COLOR SCALE OF IRON AND STEEL AT DIFFERENT TEMPERATURES

Color	Temperature (Deg. Fahr.)
Red, lowest visible in dark.....	878
Red, lowest visible in daylight	887
Red, dull..................	1100
Red, full....................	1370
Red, light (scaling heat).......	1550
Orange, full......	1650
Orange, light.....	1725
Yellow, full	1825
Yellow, light..	1950

Simple Hand-Forging Operations. In all hand-forging operations, the metal should always be heated in the forge to a temperature as high as it will stand without injury. The most common hand-forging operation is the one of reducing the cross section of a piece of heated metal and thereby increasing its length. This is known as *drawing out* the heated metal—an operation which may be accomplished much faster by working the metal over the horn of the anvil than by hammering it on the anvil face. The metal will have a tendency to flatten out too much and spread over a larger area if hammered on the face rather than the horn of the anvil. In most cases, it is desirable to increase the length of the heated metal rather than its width; hence, the suitability of the horn portion of the anvil, which has a restricted area of action.

Fig. 11 illustrates the operation of drawing out the work over the horn of the anvil. It may be observed that the rounded horn acts as a blunt edge, which forces the metal to flow lengthwise when struck by the hammer. Drawing out the work over the horn utilizes practically the entire energy of the hammer blow in forcing the metal to stretch in the most advantageous direction. The hand tools called fullers, previously described, may accomplish to a certain degree the same results as the horn. In the operation of a steam hammer, a round bar of steel may be successfully employed for the same purpose.

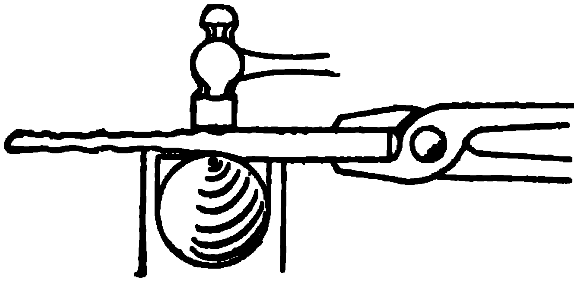


Fig. 11. Drawing Out Work over Horn of Anvil

The successive steps in drawing down a cylindrical bar of a given diameter to that of a smaller diameter are shown in Fig. 12. It may be seen in the figure that when drawing out or pointing cylindrical stock, it is best first to hammer it down square to the desired size, and then to round it to the required diameter by striking a few blows while the stock is still hot and plastic. *A* in the figure shows the original round size. *B* is the first step in hammering down the original shape to a square shape. This square shape is now hammered to an octagon shape as shown at *C*, and finally the rounding operation is shown at *D*.

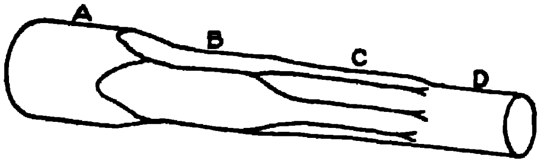


Fig 12. Drawing Down Round Bar

Fig. 13 at *A* and *B* shows the improper and proper forging of round stock. If the preliminary round stock were hammered to the final round stock without intermediate squaring, the heated material would very likely split through the center under the blows of the hammer. The effect of the blows coming down upon the stock is illustrated at *C* by the arrows *a*. The metal is squeezed together in this direction and forced apart in the direction at right angles as indicated at *C* by the arrows *b*. The proper procedure of forging round stock is illustrated at *D*.

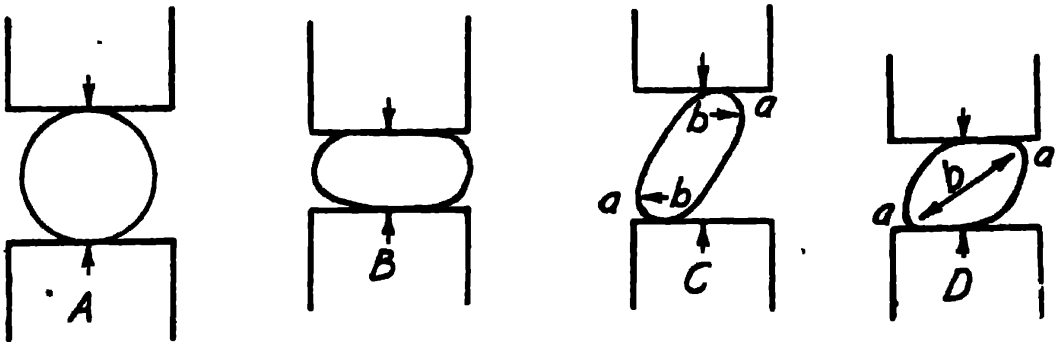


Fig. 13. Improper (*A, B, C*) and Proper (*D*) Forging of Round Stock

Another typical hand-forging operation is that of *upsetting*. This operation consists of working the heated metal in a way that its length is shortened and its thickness or width, or both, are increased. There are various methods used in upsetting heated metal. The most suitable method chiefly depends upon the size and shape of the work. When upsetting short pieces, the heated work is usually placed on one of its ends on the anvil and the upper end is then hammered directly down. If the work piece is not kept straight, there is a possibility of a bend or kink, and if any bend occurs, the metal must be straightened out before additional upsetting is carried out. When long pieces are to be upset, they are usually swung back and forth horizontally, and the upsetting is accomplished by ramming the end of the work against the anvil.

A forging operation known as *swaging* is employed when certain portions of the forged part are required to be smooth and accurate, or when cylindrical portions of the part are to be squeezed to assume an even, round, taper shape. If accuracy is not required, swaging can be done by hand with hand tools. For more accurate work and for larger sections, a pair of simple swaging forms or dies is attached, one to the anvil and the other to the ram of a steam or other power hammer. Fig. 14 illustrates a simple hot swaging operation with the aid of a pair of swaging dies. The dies shown at *A* and *B* have rounded corners, and this is a desirable feature, since the swaging will not form sharp corners in the heated metal as shown at *D*, which finally would be folded in as shown at *E*. The dies shown at *C* have correctly rounded corners, but the positioning of the work is not correct relative to the dies.

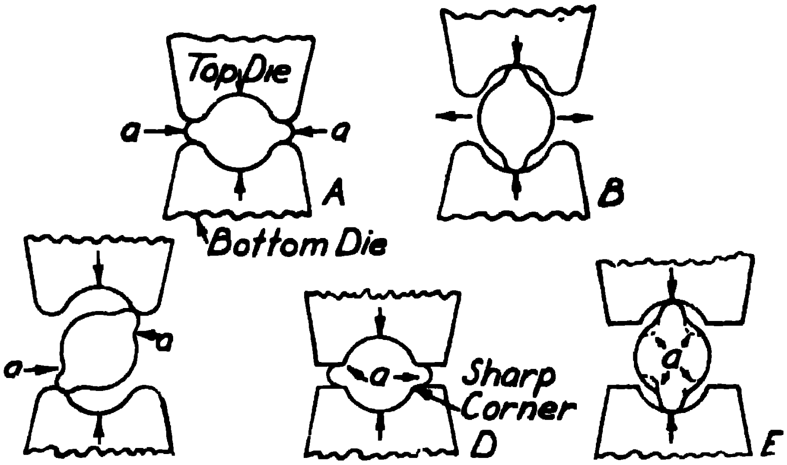


Fig. 14. Correct and Incorrect Dies and Methods of Swaging

In determining the amount of stock required to make a forged part of specific shape, any change in the density of the metal during a forging operation may be disregarded, since it is too small to consider for all practical purposes. Therefore, the volume of the metal before forging is essentially the same as that after forging, and it must be predetermined before the operation. Such volume may be computed by geometric principles.

Example. Suppose a 3-inch diameter steel bar is heated and forged by upsetting into a circular disk having a diameter of 8 inches and a thickness of 2 inches. What length of bar is required?

Solution. First, find the volume of the disk. The disk is really a cylinder, and the volume of a cylinder is found by multiplying the area of its base by its altitude. The base area is calculated by the formula $A = \pi r^2$ where A equals area, π equals 3.1416 and r^2 equals radius squared.

$$A = 3.1416 \times 4^2$$
$$A = 3.1416 \times 16$$
$$A = 50.27 \text{ square inches}$$

The altitude (height) is 2 inches. Then $50.27 \times 2 = 100.54$ cubic inches, which is the volume of the disk.

Next, find the volume of a length of the rod 1 inch long.

The rod is also a cylinder and the same procedure can be followed in finding the volume of a piece 1 inch long.

$$A = 3.1416 \times 1.5^2 \text{ (radius is } \tfrac{1}{2} \text{ of diameter)}$$
$$A = 3.1416 \times 2.25$$
$$A = 7.07 \text{ square inches}$$

The altitude of a length of the bar 1 inch long is 1 inch, because we think of this length as a cylinder having its base down. Then, $7.07 \times 1 = 7.07$ cubic inches.

Finally, if 100.54 is divided by 7.07 the result will be the number of inches of 3-inch bar necessary to form the disk. Thus, $100.54 \div 7.07 = 14.22$ inches. Call it 14.25 or 14¼ inches.

Exact reproductions of a given forging are seldom obtained in hand-forging operations because of a number of factors involved. The chief factor is that most hand-forging operations are carried out without the use of any dies. If dies are used in some cases, they are of a temporary nature and are designed simply and inexpensively without consideration of accuracy. Detailed description of forging dies is given in Chapter XIII. Another factor contributing to size variations in hand forging is the frequent omission of proper allowances for certain conditions occurring in the forging operations. Whether forging by hand or by mechanical means, allowances must always be made for the shrinkage of the heated metal when cooling in open air after forging. Similarly, as the pattern maker allows for the contraction of the cold casting made from molten metal poured into a sand mold whose shape is fashioned by the pattern, the forger must also make allowances for the contraction of the hammered metal after it is cooled to the surrounding temperature. The rates of contraction of heated metals are given in handbooks and in Chapter XVI of this text.

Welding by Hand Forging. This is a simple process used in joining two pieces of metal by means of heating the metals to their forging temperature and then hammering them together. For centuries, this process was the only means used in welding metals, and it still is used to a limited degree at the present time when hand welding is sufficient to attain the required purpose. The chief requirement for a successful hand welding is the proper heating of the metals to be joined—this must be done cleanly and evenly throughout the metal areas in contact. An excessive temperature will cause the metal to burn. A sample of burnt steel is shown in Fig. 9. An insufficient heat will prevent the metals from sticking to each other. The experience of the welder, however, will dictate the proper temperature to which the metals should be heated before hammering. The color scale of iron and steel at different temperatures was shown earlier in this chapter. In the case of unknown conditions, it is recommended to experiment first with small samples of the metals to be joined before undertaking the main task of welding.

The metal areas in contact must be free from impurities, such as dirt, oxide scale, grease, and sand particles, before the welding operation takes place. When iron or steel are heated, their surfaces will oxidize very rapidly, i.e., an oxide scale will form on their surfaces due to contact with oxygen. This iron oxide or scale will prevent the heated areas in contact from successfully sticking and forging together. However, if the portions to be joined are heated to a temperature high enough to melt the surface scale, and if these metals are properly shaped at the joint, vigorous hammering will force out the molten scale from between the two parts that are to be joined. The result will be that only clean surfaces of the heated metals will be in contact and they will stick to each other.

Very high welding temperatures may be desirable for melting the surface scale but, at the same time, they may be the chief cause of burning the metals in contact. To remedy this latter condition, suitable fluxes are used in these forge-welding operations. Fluxes are used to lower the melting point of the scale. The operation is carried out by sprinkling flux on the metal surfaces to be joined immediately before the welding heat is attained. The metal thus treated is placed in the fire again, and is heated to the welding temperature. Then the metal is hammered to make the desired weld. The flux enables the scale to melt at a much lower temperature than would be the case if flux were not used. The applied flux melts immediately and spreads over the surface of the heated metal. It forms a protective shield which guards against the formation of additional scale by keeping out the oxidizing air. Fluxes serve only to lower the melting point of scale and to prevent air from contacting the heated work. It is an erroneous belief that flux also acts as a binder or cement which makes the two contacting areas stick together.

Various fluxes have been developed to suit the wide variation in forge-welding applications. The most common fluxes are sand and borax. When welding wrought iron or machine steel, sand is found to be a suitable flux. In the welding of tool steel or fine work, borax is the best flux, since it melts at a lower temperature than sand. This low-melting characteristic makes it possible to use lower welding temperatures—a desirable feature in the welding of high-grade work. A combination of borax and ammonium chloride (sal ammoniac) is also recommended as a satisfactory flux. The usual proportion of the component ingredients of this flux is 4 parts of borax to 1 part of sal ammoniac.

The proper shaping of the contacting surfaces previous to forge welding is known as *scarfing*. The ends of the pieces to be successfully welded are so shaped, or scarfed, that they do not fit tightly before welding, but just touch in the center of the joint, leaving the sides open. When the weld is made, the molten scale is forced from between the pieces. The welding method most commonly used to join flat bars together is lap welding. The ends of the pieces are scarfed by upsetting in such a way that they are much thicker than the rest of the pieces. The purpose of this shaping is, first, to allow for the metal which may burn off and become lost because of excessive scaling and, secondly, to allow for the vigorous hammering that causes the pieces to join together. Fig. 15 illustrates the proper shape of the ends and their overlapping position previous to their being joined by hammering.

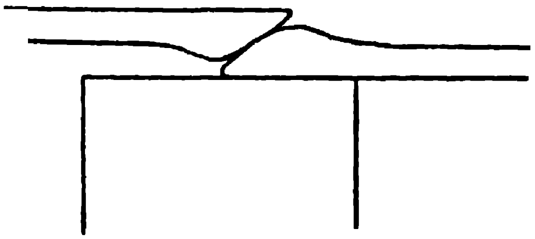
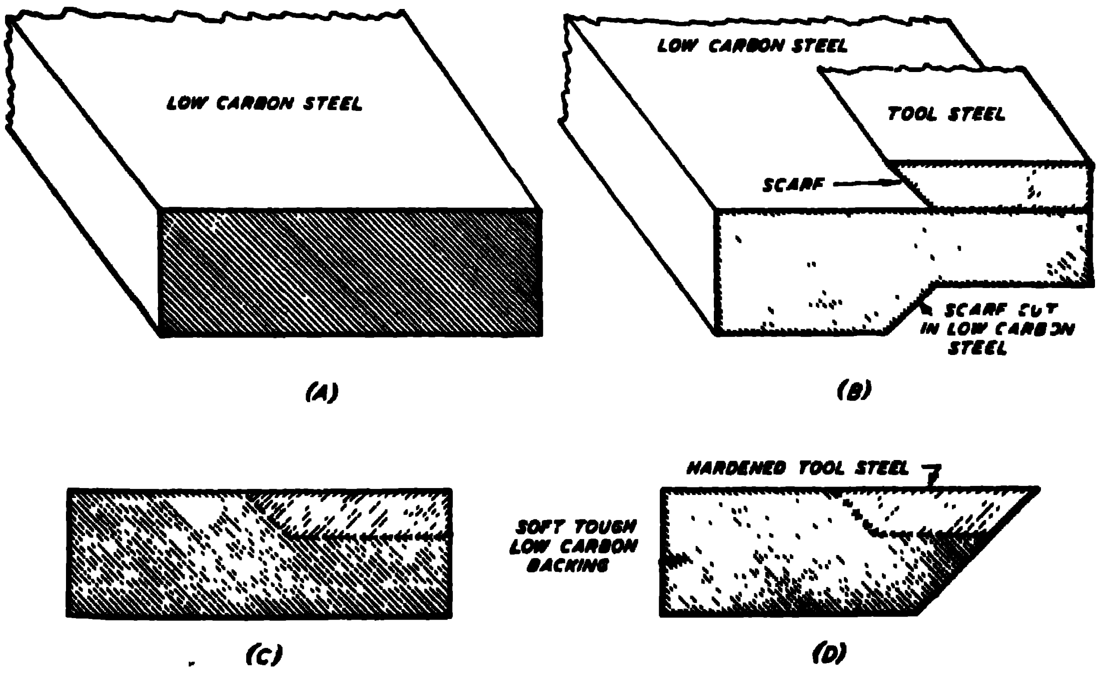


Fig. 15. Overlapping for Weld

When welding tool steel, an operator must exercise great care in heating the metal previous to working. The ends are scarfed in the same manner as other metals. A borax and sal ammoniac flux is recommended in welding tool steel. In some cases dissimilar metals may also be successfully welded, such as carbon, tool steel or alloy, tool steel to wrought iron or to low-carbon steel. The latter two metals are inexpensive as compared to the first two metals. In the manufacture of certain tools and implements, inexpensive metal may be made to serve as the backing or support, whereas more expensive metal may be needed for the tools' sharp edges or facings, which must resist wear and abrasion in service. Fig. 16 illustrates how welding of dissimilar metals is adapted in the manufacture of a machine knife. The support or back strip for the knife, shown at *A*, may be made from inexpensive low-carbon steel. The support is shaped or scarfed at a 45° angle to make a suitable joint with the tool steel, which is also scarfed at the same angle. This is illustrated at *B* in the figure, where both members are shown ready for the weld. A section of assembled parts after hammer welding is shown at *C*. The finished knife after grinding is shown in section at *D*.



(A) (B)

(C) (D)

Fig. 16 Welding in the Manufacture of a Machine Knife

Welding of dissimilar metals is common in the manufacture of numerous, edged tools used in various industries—tools such as knives, blades, chisels, and others. There are definite advantages derived from this practice. The cost of the product is reduced at no sacrifice of its quality. Usually, only the working portion of the tool is heat treated; the soft backing allows for straightening after the heat treatment. The soft backing also insures a much stronger finished tool. Another illustration of hammer welding of an expensive, tool-steel blade to an inexpensive low-carbon-steel holder or ferrule is shown in Fig. 17.

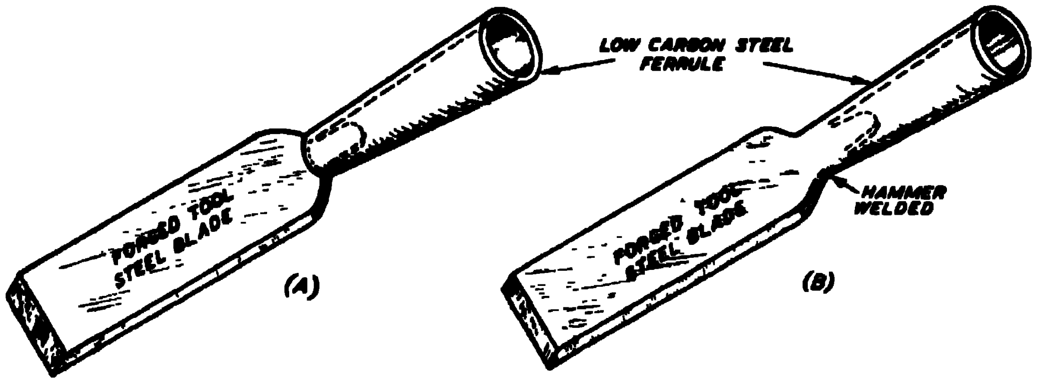


Fig. 17. Hammer-Welded Blade and Ferrule of Wood-Working Chisel

Tool Forging by Hand. Numerous tools, such as lathes, shapers, and planers—various chisels for work on metal, stone, and other materials—tools used in the cutting and carving of wood, are in most cases hand forged by hammering to desired shapes. Afterward, they are rough ground, hardened, tempered and, finally, ground to the exact shape and required keenness. The methods used in hand forging these tools are essentially the same as those previously described. The proper heating of the stock in the furnace before hammering is an important prerequisite for successful forging. Correct temperatures of the furnace and of the metal, both at the beginning of forging process and at the end, proper handling of the equipment, etc., are observed with greater exactness in making keen-edged tools than in forging ordinary products.

Many grades of steel, both plain carbon and alloy, are employed in the making of tools by hand forging. For economy reasons, plain-carbon tools are satisfactory if the tools are employed in light service and are not subjected to the influence of high temperatures, high speeds, and other conditions detrimental to this type of material. The carbon content is usually high, 0.90 per cent for chisels and about 1.20 per cent for cutting tools on machines, such as lathes, shapers, and planers. In the forging of a chisel, the steel stock is first heated in a suitable forge or furnace to a good yellow heat and then is hammered into the required shape and finished smoothly before the metal cools off appreciably. Since the equipment to hand forge a tool consists only of an anvil (particularly the horn) and hammers, as shown in Fig. 18, skill in heating the stock and holding it over the anvil properly is required. An experienced craftsman—one familiar with the behavior of heated metal—is usually called upon to carry out the operation, especially if high-grade, expensive tools are to be hammered to shape. Fig. 18 illustrates the method and steps followed in hand forging a cape chisel.

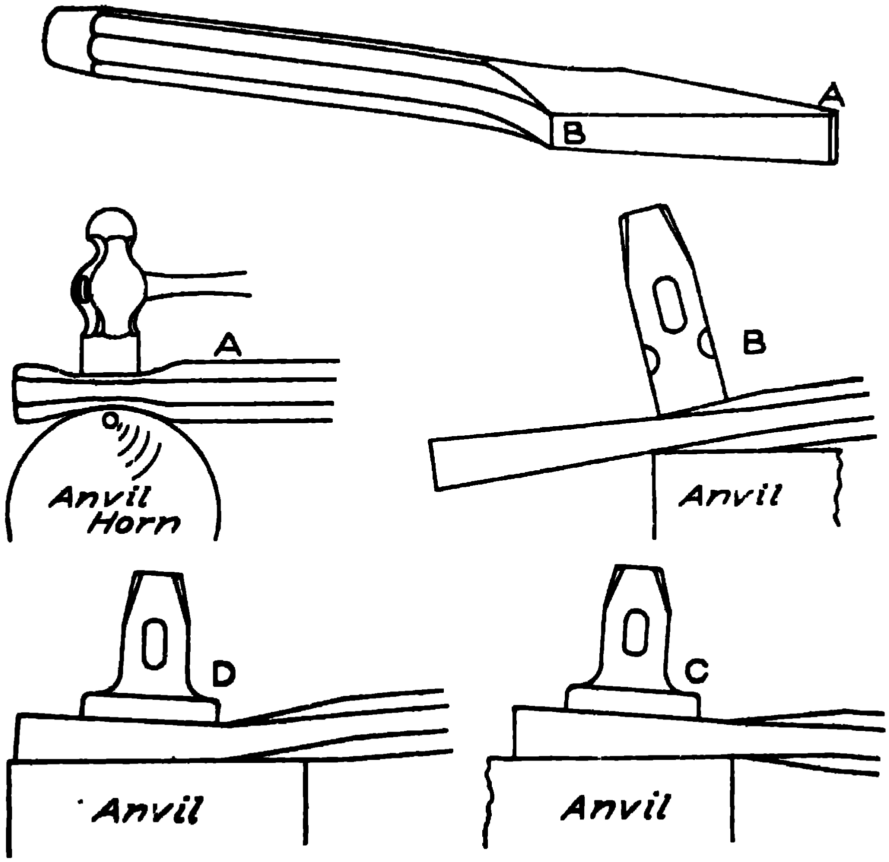


Fig. 18. Method of Forging Cape Chisels

The completed tool is shown at the top of Fig. 18. The first step consists of hammering a portion of the stock over the anvil horn, as shown at *A*. Other portions of the work are, then, progressively hammered on the wider surface of the anvil as shown at *B*, *C*, and *D*.

Fig. 19 shows the method of forging a typical cutting-off tool. The hammering of the thin portion of the tool over the anvil is shown at *A*. The position of the hammer relative to the work should be noted in the illustration. The completed tool is shown at *B*.

Fig. 20 shows the method and steps used in making the general shape of a diamond-point tool. The shape is started by using a bottom fuller, working the stock down about one-third, as shown at *A*. The rounded edge of the anvil may also be used in place of the fuller.

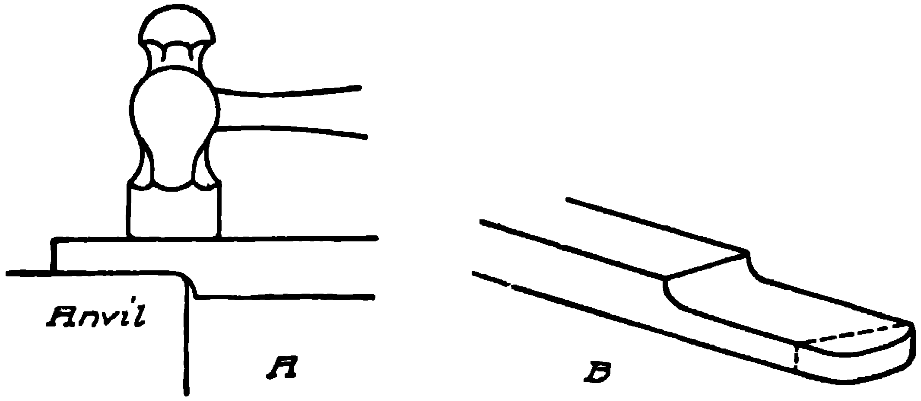


Fig 19 Method of Forging a Cutting-Off Tool

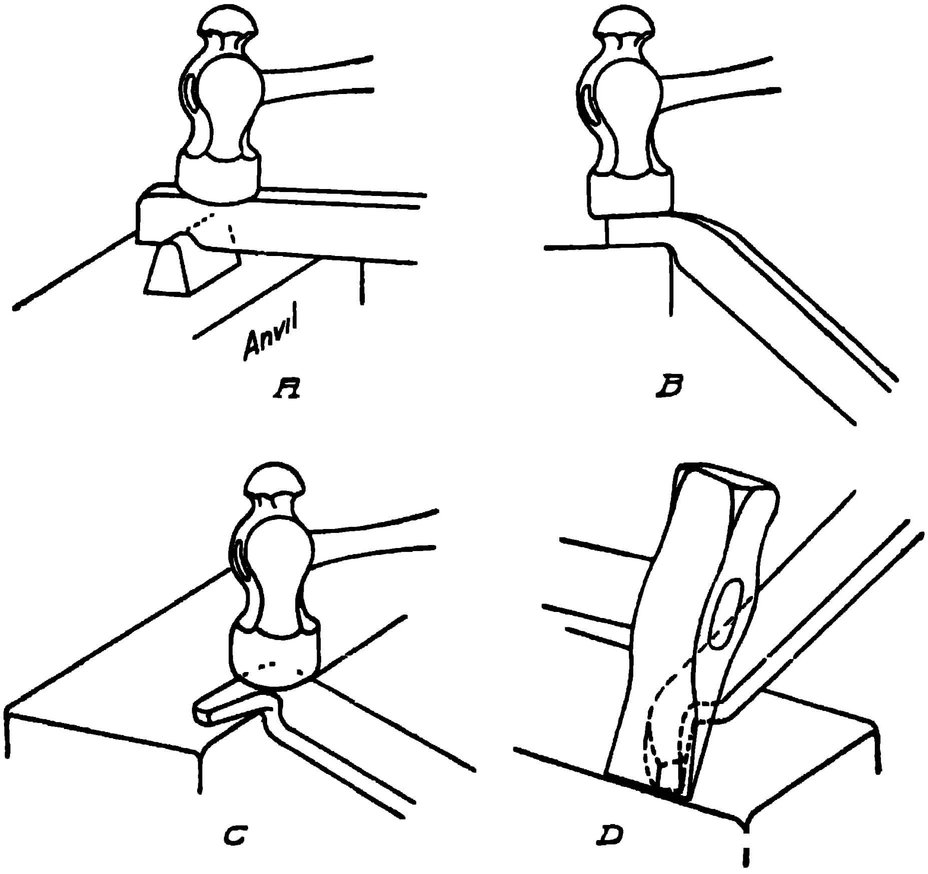


Fig. 20. Method of Forging a Diamond Point

The point is formed then, as shown at *B*, and turned on the side, as shown at *C*, for starting the diamond shape. Both sides of the tool are worked until the proper shape and size are formed as desired. Finally, the tool point is placed on the flat side on the anvil and, with the aid of a hot chisel, the point is cut to proper length, as shown at *D*.

Fig. 21 shows the method of forging a side tool. The operation is started by drawing down a point endwise, as shown at *A* in the illustration. The point is hammered out at the corner of the anvil so that it can be drawn small without striking the corner of the hammer into the anvil. The work is then brought to the flat horn of the anvil for sharpening or drawing out thin on one side. At *B* is shown how part of the face of the hammer is extended over the edge of the anvil so that all of the recess in the work will occur on the side that is down. Next, the tool is placed on the anvil as shown at *C*, and its top edge is bent over to get the proper side-clearance, as shown at *E*. *D* shows how the completely forged tool is quenched in a cold liquid, water or oil, after heating it to the hardening temperature. This temperature may be recognized by the color of the heated tool. It varies from a full red to a light red. The color scale of steel was shown

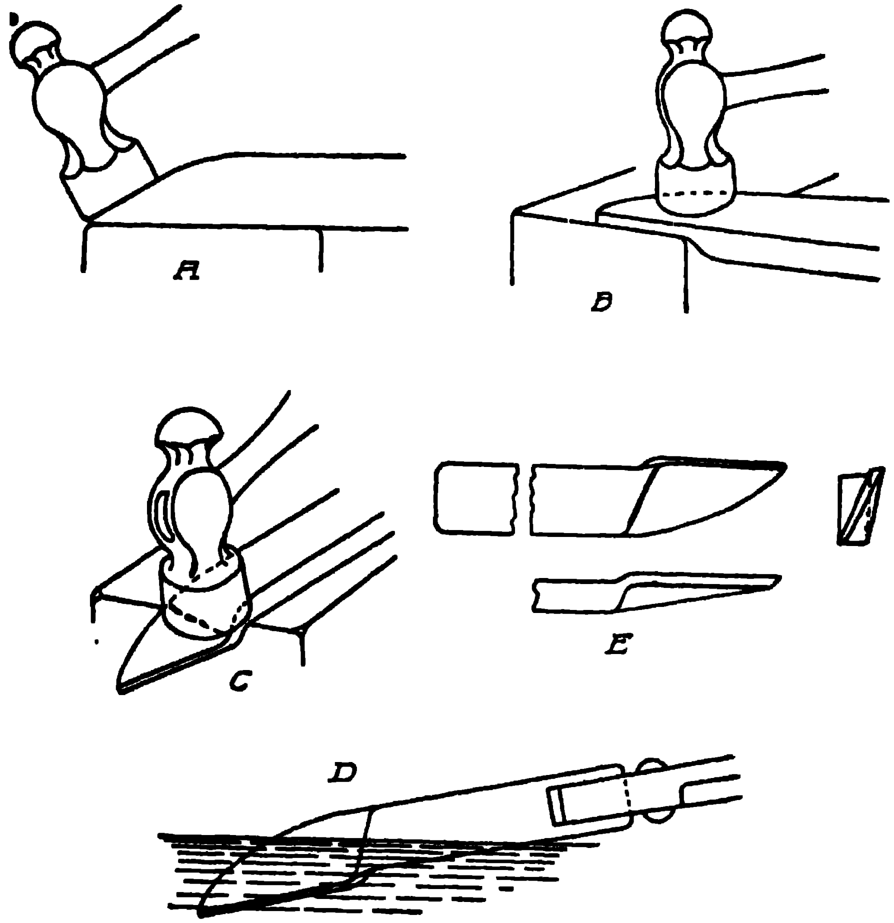


Fig. 21. Method of Forging and Hardening a Side Tool

earlier in this chapter. The heating of the tool and the rapid quenching hardens the metal. After hardening, the tool is reheated to a lower temperature than that of hardening, and then is cooled to room temperature. This last operation *tempers* or *draws* the metal, i.e., it reduces the hardness but increases the toughness of the tool. Tempering temperatures vary, depending upon the degree of tempering or drawing that it is desired to achieve in a product. Such temperatures may be as low as 400° F. or as high as 1200° F., or even higher.

Of course, production tools used in large quantities are forged by means of power hammers and precise dies. The accuracy of the tool shape is assured by the workmanship of the dies. Forging dies are expensive, but their cost is warranted, since they are used in large volume production of required parts. High-production tools are made from material of superior quality—stock that will withstand high temperatures encountered in high-speed machining and that will resist wear, abrasion, and other detrimental effects.

REVIEW QUESTIONS

1. Describe briefly the operation of hand forging.
2. Name some of the principal tools used in hand forging.
3. Describe briefly the operation of a blacksmith's forge.
4. Sketch the operation of drawing out a piece of simple work over the horn of an anvil.
5. Make simple sketches of the successive steps in drawing out a cylindrical bar of given diameter to a smaller diameter.
6. Make two illustrations showing proper and improper forging of round stock.
7. Describe the forging operation known as upsetting.
8. Describe the forging operation known as swaging.
9. Calculate the length of a steel bar, 2½" in diameter, heated and forged by upsetting into a circular disc 6¼" in diameter and 1⅞" thick.
10. Explain briefly the operation of welding by hand forging.
11. What is a good temperature at which to weld steel pieces together by hand forging?
12. Name some of the fluxes developed for forge-welding steel, and mention the advantages of using them.
13. Sketch the shaping operation known as scarfing that is performed on the ends of two steel pieces for the purpose of forge-welding them together.
14. Make a simple sketch illustrating the operation of hammer welding a tool-steel blade to a low-carbon-steel holder.
15. How are production tools forged in large quantities?

CHAPTER IV

Power-Hammer Forging

The Smith Forging Method. Power-hammer forging has replaced hand forging where the working and shaping of metal, particularly steel, requires a substantial amount of power. Power-operated hammers are especially suitable for shaping steel sections which require a considerable reduction in cross section, with or without definite form changes. The work performed is similar to that of hand forging in every respect, except that the tools are manipulated by power, which may be belt driven or operated directly by air or steam. Simple, flat dies of inexpensive design are used to facilitate the forging operation. Two dies are used—one is attached to the movable ram or hammer, and the other is mounted on the stationary anvil of the machine.

The type of metal forging that is commonly known as smith forging of hot working steel consists of hammering heated steel between a pair of flat dies. Accuracy in shaping the forged part depends a great deal upon the skill of the operator or hammersmith in his ability to manipulate the heated metal around in order to develop the required shape in the least amount of time before the metal cools off. It is true that some of the shape of the forged part is obtained by the use of suitable hand tooling, but the major shaping is accomplished by the hand manipulation of the experienced smith. In these operations, the forgings are produced to approximate sizes, and subsequent machining is required to finish them, especially when accuracy is demanded.

Smith forging is suitable to the type of production where quantities are small and the finished shape and size of the required product can be completed by subsequent processes, such as machining or grinding. This method of forging is also recommended where sizes of the work are too large or irregular to be produced by means of modern forging methods employing accurate closed-impression dies. Smith forging embraces operations on pieces of work ranging in size from small forgings weighing less than a pound to extremely large forgings whose weight may exceed 200 tons. The general range of smith forgings is produced on steam smith hammers of the open-frame type. Hydraulic forging presses are recommended as best for very large forgings. Small forgings of simple design are also produced by some manufacturers on small machines called *helve hammers*. Fig. 1 shows a single or open-frame smith hammer which uses plain or flat dies. This hammer is operated by steam.

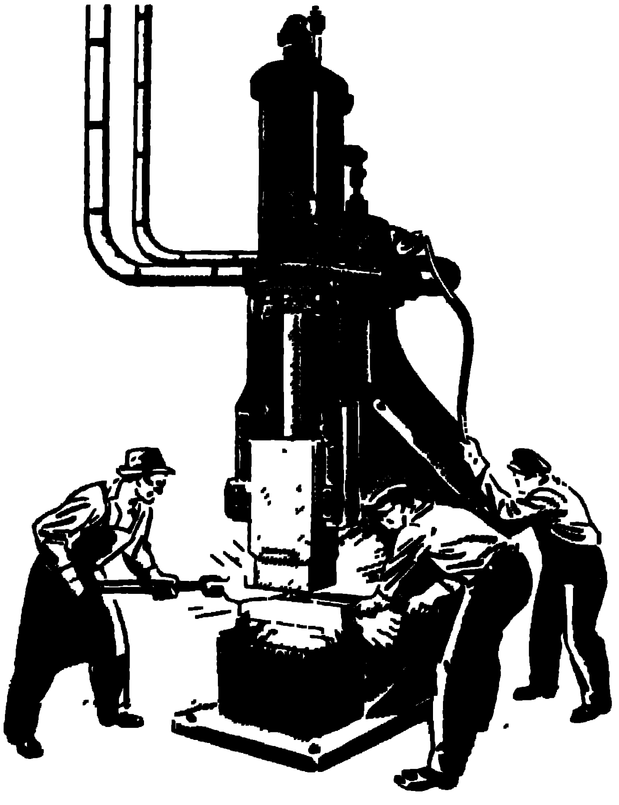


Fig. 1. Open-Frame Smith Hammer, Using Plain or Flat Dies in Operation

Courtesy of Drop Forging Assn. Cleveland, Ohio

Smith hammers are also built in the double-frame type, these are appropriate for shaping heavier forgings. Smith hammers of all types are found by some large producers of forgings to be suitable equipment for preliminary operations on parts which will be forged to final shape in closed impression dies. They are also found suitable for production on small-run jobs such as the shaping of simple shafts or rings on which subsequent machining or grinding will be required to finish them to specifications.

Steam Hammers. Steam hammers, one of which is shown in Fig. 1, operate on the principle of the steam engine. The principal parts of the hammer are a rugged frame, a steam cylinder, a piston, and a piston rod. The hammer is attached to the piston rod, and is raised by admitting steam beneath the piston. The downward stroke of the hammer is obtained by exhausting the steam from beneath the piston and admitting it above. The hammer is accelerated by gravity and by the steam pressure exerted above the piston. Steam pressures range from 75 to 125 pounds per square inch. In order to vary the hammer blows from a light tap to a heavy strike, steam can be admitted below the piston while the hammer descends, thus creating a cushion for absorption of the momentum of the falling hammer.

Hammers are produced in many sizes and are rated by weight of the parts which fall during the downward stroke. These parts are the piston, rings, rod, hammer, and upper die. Hammer weights vary from 200 pounds to 50 tons, depending upon the size and type of steel to be forged. A quick estimate of the hammer weight in this type of equipment is made on the basis of 50 pounds minimum falling weight per square inch of the cross-sectional area of the metal being hammered. For example, assume a steel bar having a cross-sectional area of 5 x 7 inches; then, the minimum weight of the hammer required to forge this metal should be $50 \times 5 \times 7 = 1{,}750$ pounds. This method of computing the approximate falling weight applies only to this type of forging. In production forging which employs closed-impression dies, the computation is more complex because of numerous factors which are encountered there.

The single or open-frame steam hammer, also called the single-arch hammer, shown in Fig. 1, has its cylinder supported on a half-arch frame. As previously stated, it is the machine mostly employed in this type of forging. Because most of the impact is absorbed by the machine and its foundation, the steam hammer must have a foundation that is strong, well-constructed, and set deep in the ground. The foundations for large hammers may have to be sunk to bed rock. Fig. 2 shows a typical foundation for the anvil and frame of a single-frame-type steam hammer. Two piers are required to support the hammer, while the anvil rests on a third pier entirely separate from the others.

Small steam hammers have the anvil and frame cast integrally, but large hammers have a separate anvil made from cast iron which rests on a deep-seated foundation, while the frame has a separate foundation. The frame is made from alloy cast iron and the moving parts, such as the piston rod, are made from alloy steel. The anvil is generally about 20 times heavier than the weight of the falling parts. For example, a 12,000-pound hammer would be adequately backed by an anvil weighing 240,000 pounds.

The dies for steam hammers are made from special alloy steel. Such steel is able to resist the influence of the high temperatures to which the forged parts are heated; also, it is able to withstand the high-impact blows of the hammer on the anvil. These dies are machined, hardened, and ground to accurate dimensions.

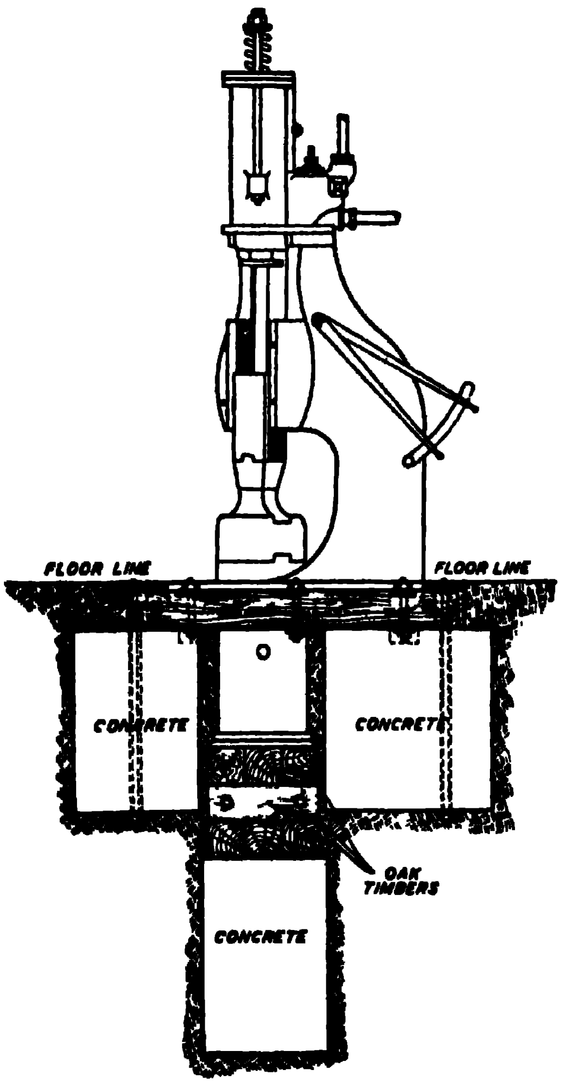


Fig. 2. Foundation for the Anvil and Frame of a Steam Hammer

The smaller steam hammers are successfully employed for producing many types of forgings. They are very suitable for tool forging, knife welding, and similar work. The large steam hammers are suitable for heavy forging, including the reduction of alloy-steel and tool-steel ingots into bars and billets for the rolling mill or drop-forge shop. Gun forgings, diesel-engine crankshafts, large connecting-rod forgings, and other large and heavy work are usually shaped by the large steam hammers. Fig. 3 shows a large double-frame steam forging hammer in operation. The steam cylinder in this machine is located in such a way that it is supported centrally in a complete arch.

Motor-Driven Air Hammers. Compressed air instead of steam can also be employed in the operation of the smaller-type hammers previously described. The air pressures employed to motivate forging hammers generally range from 100 to 110 pounds per square inch. Certain advantages may be gained by using air-operated hammers instead of steam hammers. These are as follows:

1. No dripping of water occurs on the steel dies and other vital parts. Water causes cracking and other possible defects.

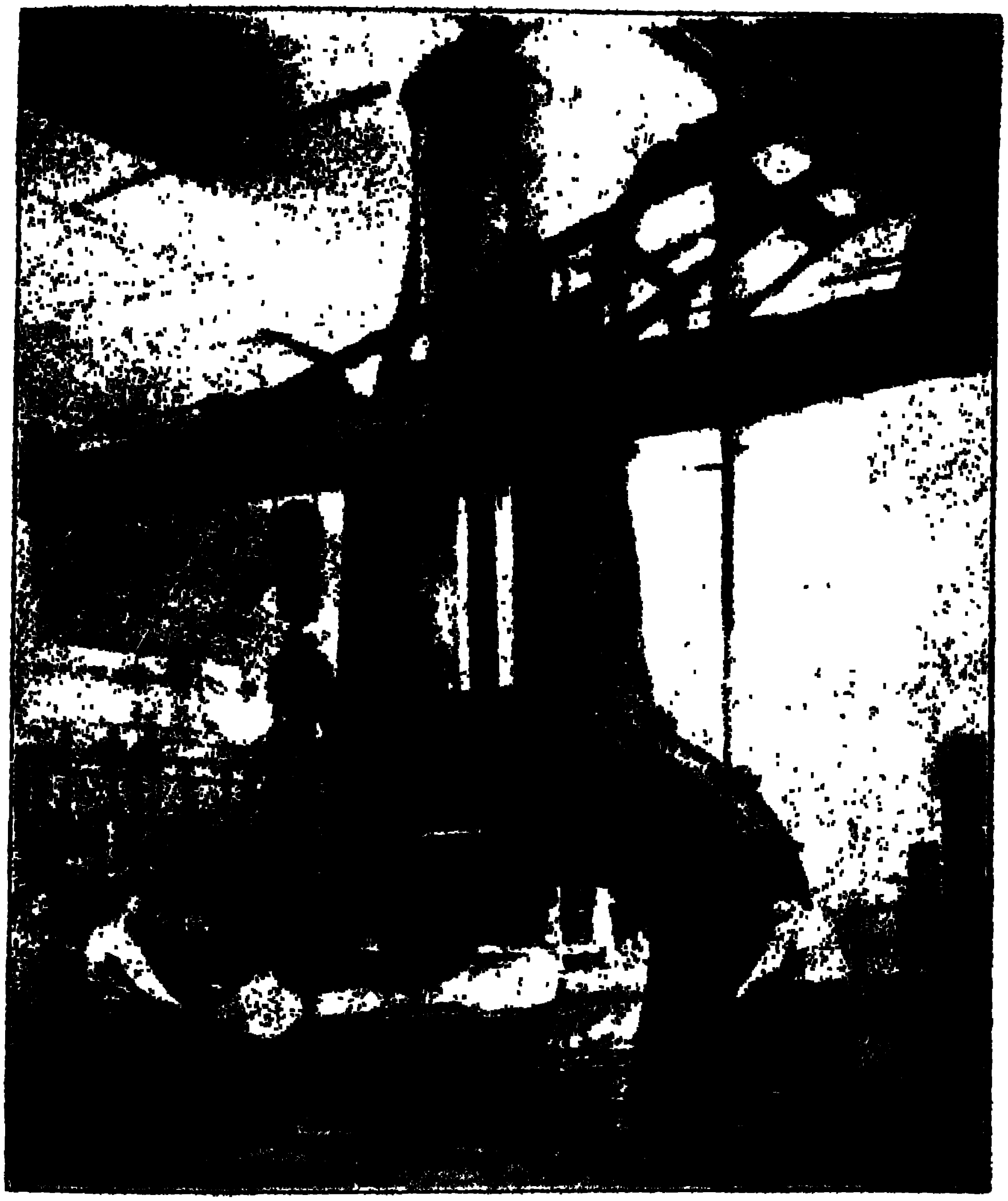


Fig. 3. Double-Frame Steam Forging Hammer
Courtesy of Erie Foundry Company, Erie, Pa.

2. Air-operated hammers do not require frequent repacking, whereas steam hammers cannot operate long without repacking, which is a costly operation.

3. Individual air hammers are more convenient to operate independently in the shop—separate from the rest of the hammers and their combined equipment. Many of these individual machines are

built with the hammer and air compressor combined in one unit, and there is no interdependence with other machines.

Fig. 4 shows a motor-driven air hammer in operation. The frame of this hammer is properly proportioned, broadening out from the cylinder at the top to the bed plate at the bottom. The bed plate is cast integral with the frame. This design provides rigidity of construction. The operating mechanism, including the driving motor,

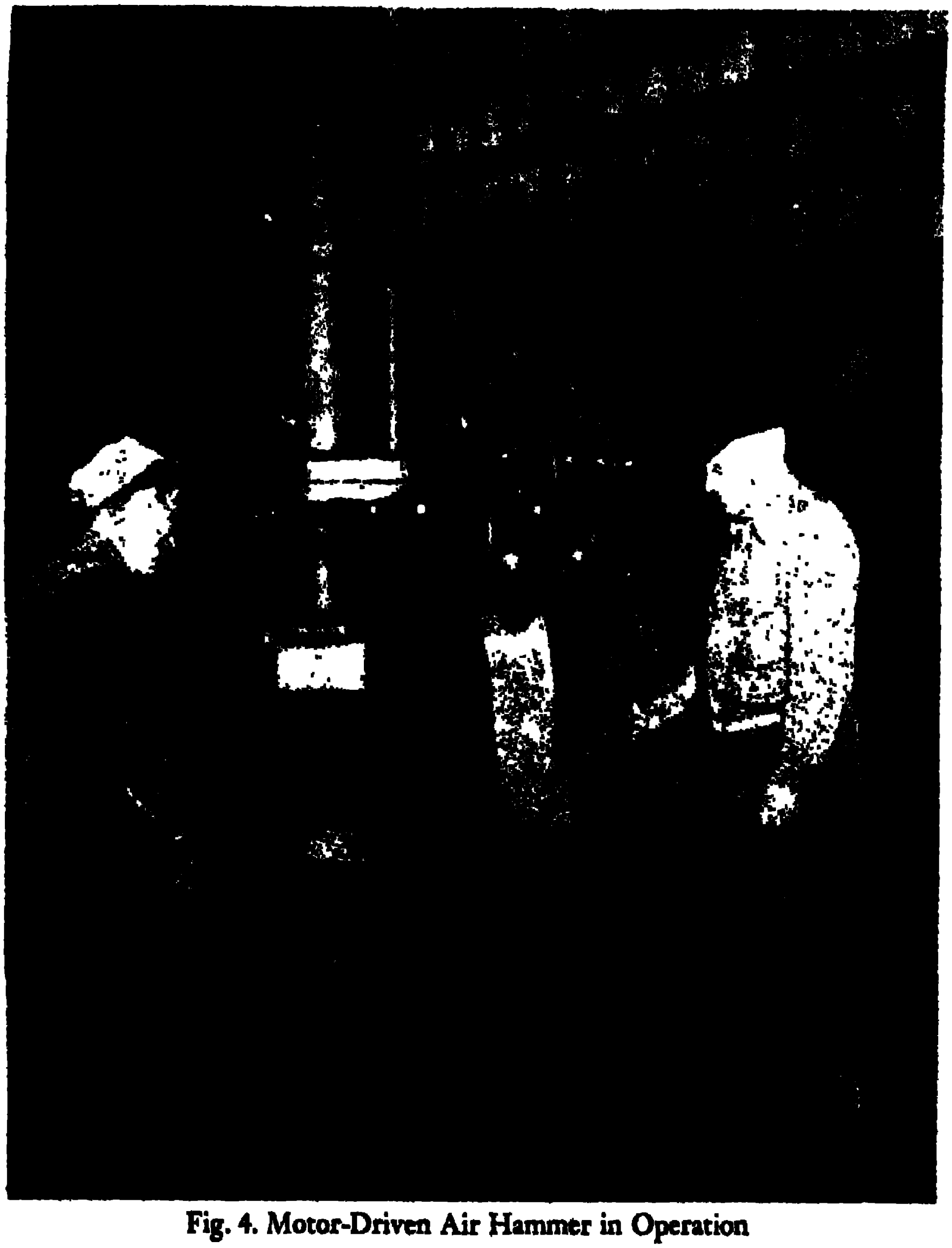


Fig. 4. Motor-Driven Air Hammer in Operation
Courtesy of Erie Foundry Company, Erie, Pa.

is housed inside the frame. The entire machine, composed of the hammer and the air compressor, is designed as a compact unit. The air temperature in such a hammer is the same as the air temperature in the compressor and, because of practically perfect expansion, the air delivers nearly the full power which it obtains in the compressor.

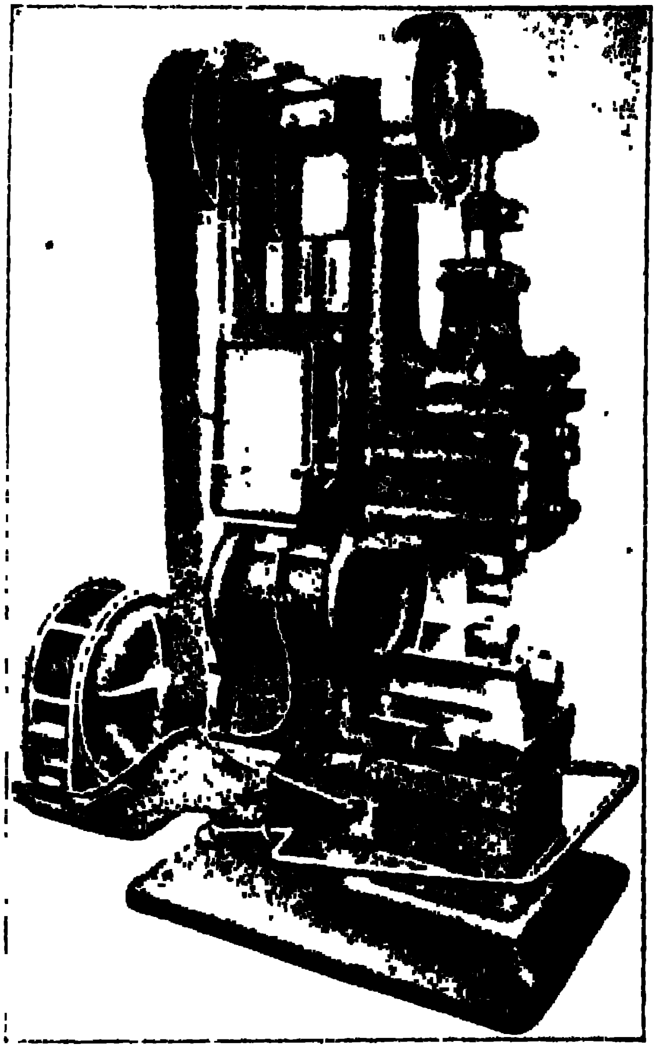


Fig. 5. Small Power Hammer

Small Power Hammers. Small power hammers are designed for light forging operations. These machines are of several types, but most of them are operated mechanically. Fig. 5 shows a typical, small power hammer which is operated by an adjustable crank. A connecting rod attached to the crank applies motion to the hammer head. A heavy spiral spring is used to obtain an elastic blow, which removes danger of breakage and also prevents undue shock to the machine.

Another power hammer is shown in Fig. 6. It is of compact construction and occupies a small area. The motor is mounted on a separate stand, free from all the vibrations of the hammer, thus insuring long life to the electrical equipment. Force and elasticity are given to the blow of the hammer by careful design of the operating mechanism and by providing rubber cushions which insure the working parts against jar and concussion, thus reducing their wear and breakage. There is an important safety feature in a design of this type. Substitution of rubber cushions for the steel spring eliminates entirely the hazard of injury which may be caused by flying pieces of crystallized metal. The positive operation of the hammer is obtained by connecting its head or ram with the crank. The length of the stroke is adjusted by shifting the position of the crank pin in the slot in the balance wheel as shown in the photograph. The adjustment makes it possible to obtain strokes of various length. Sometimes short, quick, snappy blows are required; at other times, full-length strokes are needed. Fig. 7 illustrates some of the shapes that may be forged on small power hammers.

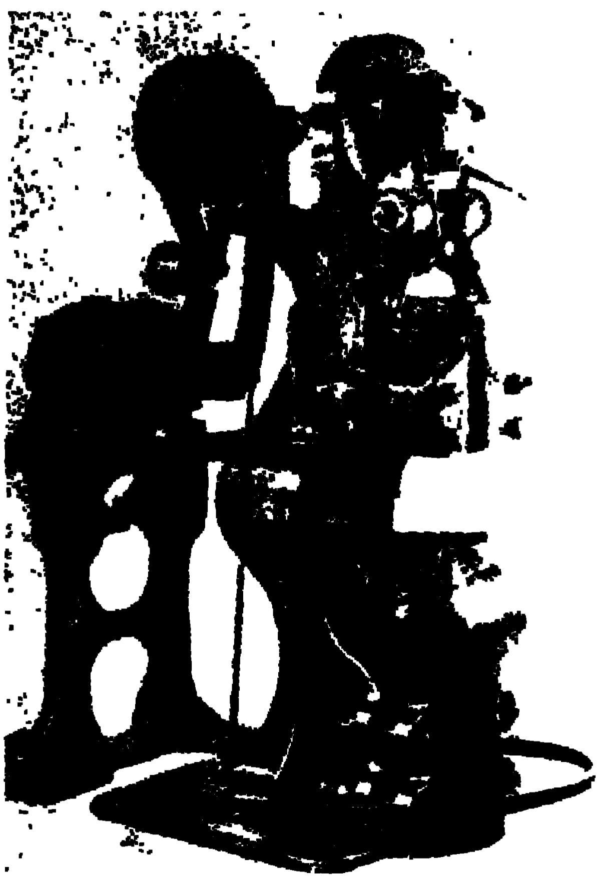


Fig. 6. Motor-Driven Compact Hammer
Courtesy of C. C. Bradley & Son, Inc., Syracuse, N.Y.

Power-Hammer Tools. Suitable tools are important in all power-hammer operations. Fig. 8 illustrates the common shape of hot chisels for use under power hammers. The handle and blade are sometimes made from one piece of tool steel as shown at the top of the illustration. Sometimes the blade is made of tool steel and is welded to an iron handle, as shown in the lower part of the illustration. The handle next to the blade should be flattened out to give the effect of a spring which will allow a certain amount of flexibility when the chisel is used under the hammer.

The chisel blades should be of proper form for best performance. The edge of the blade should be square across and not rounded, as shown at *A* in Fig. 9. Sometimes for special work the edge may be slightly beveled as shown at *B* and *C* of the illustration.

Fig. 10 shows the shape of a chisel designed for cutting or nicking bars that are not heated. The tool is made very flat and stumpy, which shape gives the tool sufficient strength to resist the crushing effect of heavy blows that are administered in forging operations.

Fig. 11 shows a chisel designed for cutting into corners. Similar tools, having slight modification of shape, may be used for bent or irregular work.

Fig. 7. Typical Forgings Made with Small Power Hammers

Courtesy of the Barbour-Stockwell Company, Cambridge, Mass

Fig. 12 shows the method used for cutting off hot stock. *A* demonstrates how the work is cut nearly through by the use of a suitable chisel. The work is then turned over and a similar chisel is placed on top of the worked piece. A quick heavy blow of the hammer drives the chisel through the work and carries away the thin fin shown at *B* of the figure. This operation leaves both of the cut ends clean and smooth.

The tools used for shaping work on power hammers are generally simple and inexpensive. Among these tools *swages* are in common use. Some of these tools for finishing work up to 4 inches in diameter are shown in Fig. 13. The completed tool is shown at *A*.

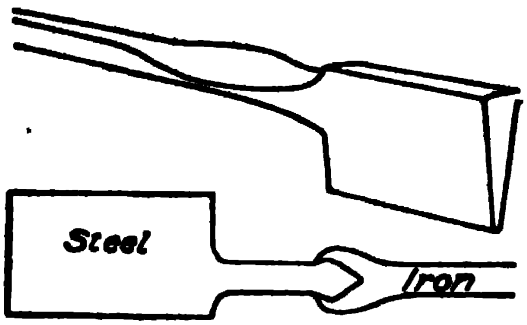


Fig. 8. Stream-Hammer Chisels

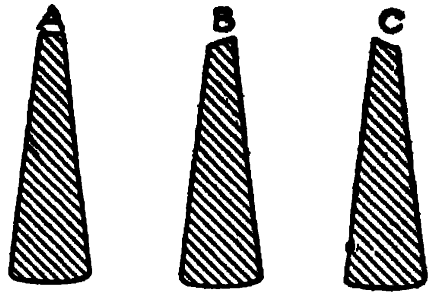


Fig 9 Sections of Chisel Blades

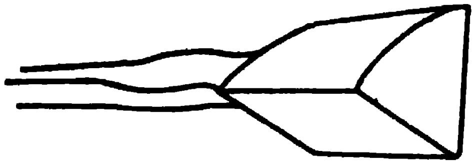


Fig. 10. Chisel for Cutting Cold Bars

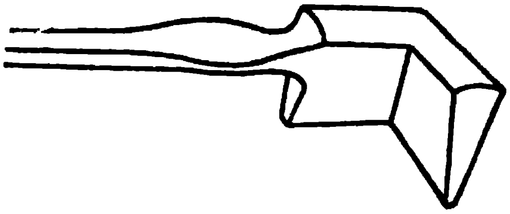


Fig. 11. Chisel for Cutting into Corners

The handle of the swaging tool is formed in the shape of a spring and may be made either in one piece with the swaging blocks as shown at *C*, or may be inserted as shown at *B*. This kind of swaging tool is known in the industry as a *spring tool.*

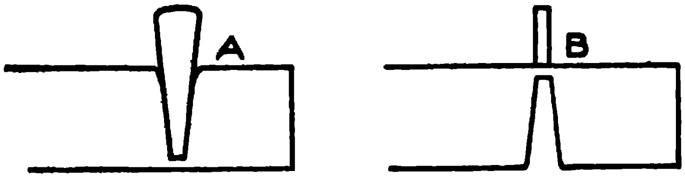


Fig. 12. Method of Cutting Off Hot Stock

Fig. 14 illustrates another design of swaging tool. *A* shows the top swage and *B* shows the bottom swage. A swage of this design is used over a die block which has a square hole cut in its face. The portion of the bottom swage marked *X* fits into this square hole. The other two projections of the bottom swage fit over the edge of the anvil block.

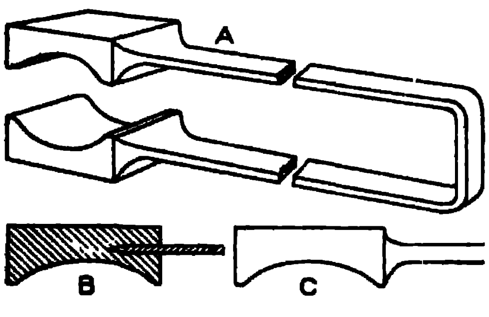


Fig. 13. Swage for Power-Hammer Work

Fig. 15 shows a tool for tapering or fullering work under the power hammer. The faces of the anvil and hammer dies in power-hammer work are flat and parallel. Therefore, work that requires tapering or fullering operations must be finished by means of tools shown in the figure.

Fig. 16 shows the method of tapering and fullering with the aid of proper tools. The roughing of the piece is carried out with the round side of the tool turned down, and the finishing operation is completed with the flat side. Whether done with a hand hammer or a power hammer, fullering calls for manual dexterity.

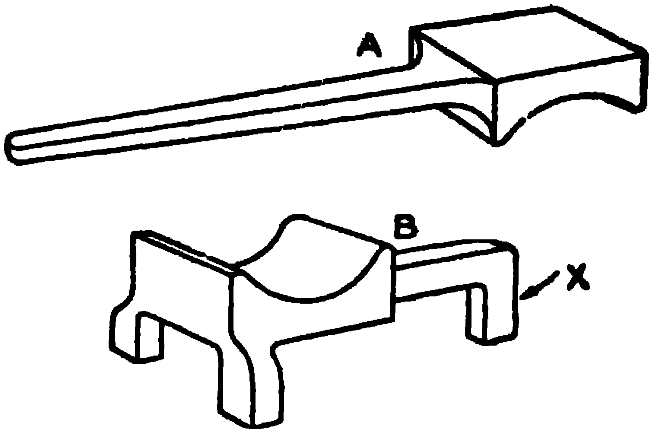


Fig. 14. Swage Used on Die Block

Fig. 17 shows the method of using round bars for grooving or necking work produced on steam hammers. These tools are used instead of fullers—the latter are more suitable for grooving ordinary hand forgings. One round bar is used if a groove is required on one side only. The proper positioning of the tool relative to the work is important before the hammer blow is applied. For best results, the hammer is applied lightly at first, in order to insure a definite and steady bearing between the tool and the work. Afterward, heavier hammer blows are delivered to complete the required task.

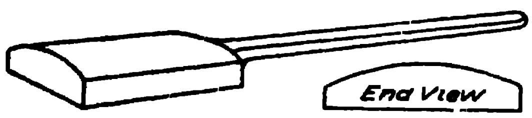


Fig. 15. Tool for Tapering or Fullering under Power Hammer

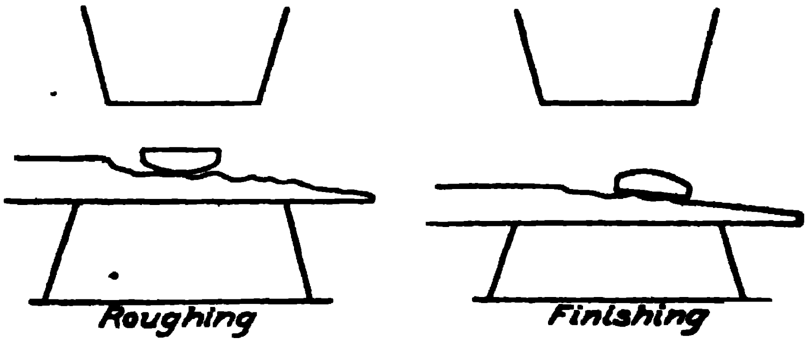


Fig. 16. Method of Using Tapering and Fullering Tool

Fig. 18 illustrates the steps followed in squaring up work. This operation is necessary at times when the hammered work shifts to the side or becomes distorted in some other manner as shown at *A*. To rectify this irregularity and correct the shape of the work, the distorted bar should be put under the hammer and formed to a shape shown at *B*. The next step consists of rolling the piece in the direction indicated by the arrow until the shape at *C* is obtained. Finally, the piece is formed square as shown at *D*, and this is the finished required shape.

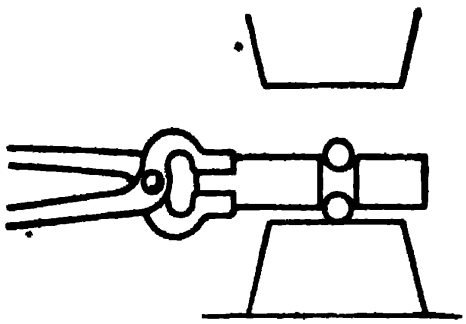


Fig. 17. Using Round Bars for Grooving or Necking

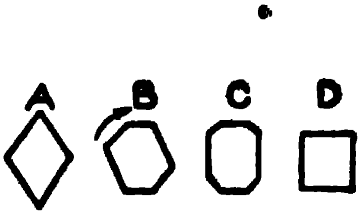


Fig. 18. Steps in Squaring Up Work

REVIEW QUESTIONS

1. Describe briefly the switch-forging method.
2. What are plain or flat dies?
3. Describe the operation of steam hammers.
4. Estimate a steam-hammer weight on the basis of 50 pounds minimum falling weight per square inch of the cross-sectional area of the metal being hammered, which is 6" x 8". Flat dies are used.
5. Calculate the weight of the anvil of a 10,000-pound steam hammer.
6. Explain briefly the operation of a motor-driven air hammer.
7. What are the three main advantages gained when using air-operated hammers instead of steam hammers.
8. Describe the operation of a small, mechanically operated power hammer.
9. Name several simple power-hammer tools.
10. Sketch a set of simple power-hammer tools known as swages.
11. Sketch the method of using a round bar for grooving or necking work produced on a steam hammer.
12. Sketch the operation of squaring hammered work distorted in the process of being forged to shape.

CHAPTER V

Impact-Die or Drop Forging

The Drop-Forging Process. Drop forging consists of hammering heated bars or billets of steel and other metals within closed-impression dies. The action of this process is that of actually kneading and forming the hot plastic metal with the aid of carefully machined and ground dies. These dies impart proper shape and size to the worked pieces. Intermittent-impact pressure of the hammer blows refines the steel billet or bar and improves the physical properties of the metal. This improvement is effected in any metal, particularly steel, that is worked through successive forging stages from preliminary operations to attainment of the required shape in the finishing impression of the die.

The drop-forging process of hot working metals is employed in producing forgings ranging in weight from less than one ounce to several hundred pounds. The work materials of the process include any of the malleable compositions of iron and steel, alloy steel, stainless steel, brass, bronze, and many aluminum and magnesium alloys. Steel bars or billets are transformed by forging into a host of articles and fixtures, including essential parts used in automobiles, airplanes, railroad cars, engines, agricultural implements, and household appliances.

Many metals may be forged by this process, but steel, when rendered plastic by heat, is the metal best adapted to drop forging. Large quantities of high-quality forgings of identical kind may be rapidly and economically produced in any shape that will allow removal of the forging from the die. The quantities, however, are not restricted to large volumes only. It may be possible to forge economically even small quantities of parts, especially when the chief purpose of forging is not only imparting shape to the product, but also effecting the necessary improvement of its physical properties in order to meet service requirements. The quantities, therefore, may vary from a few to millions of duplicate pieces. The varieties of shapes and sizes that can be drop forged are almost limitless, and it is no longer assumed that a particular part cannot be drop forged until the possibilities have been thoroughly surveyed.

The equipment needed to perform drop-forging operations consists primarily of a machine or hammer, which may be either a *board hammer* or a *steam hammer,* and a set of forging dies designed for a product of given shape. The board hammer is a gravity-type drop-forging machine. The ram carrying the upper-impression die is fastened to hardwood boards which pass between sets of rotating rolls in the top of the hammer. Pressure of the rolls against the boards raises the ram and upper die to a height from which the operator releases it to strike the forging blow. This blow results from the force gathered by the freely falling ram and upper die in their descent upon the stationary lower die. A detailed description of the board hammer is given in this chapter.

Forgings of any geometrical form which permits removal from a die can be made by this process. Any metal possessing plasticity, whether it is heated or cold, may be drop forged. Steel, made plastic by heating, is the usual metal for forgings.

The Advantages of Drop-Forged Products. The selection of the drop-forging process to produce a desired part is based on one or a number of essential factors, which may be enumerated in the order suggested by the Chambersburg Engineering Company in their 1950 publication *Impact Die Forging:*

1. Greater strength.
2. Reduction in weight of finished part.
3. Ability to withstand unpredictable loads.
4. Minimum of machine-finish required.
5. Saving in material.
6. Elimination of internal defects.

Concerning factor 1, a part which is drop-forged with the aid of dies is substantially stronger than a casting of the same cross-sectional area. Because of this fact, a drop forging may be designed with a considerably smaller sectional area, thus saving on the amount of metal required and reducing the cost of the part.

Concerning factor 2, when comparing parts, all designed for the same working loads, but each designed for different fabricating processes, it will be found that a drop forging will be much smaller and lighter in weight. Therefore, when the design calls for great strength and light weight, a drop forging will often be selected.

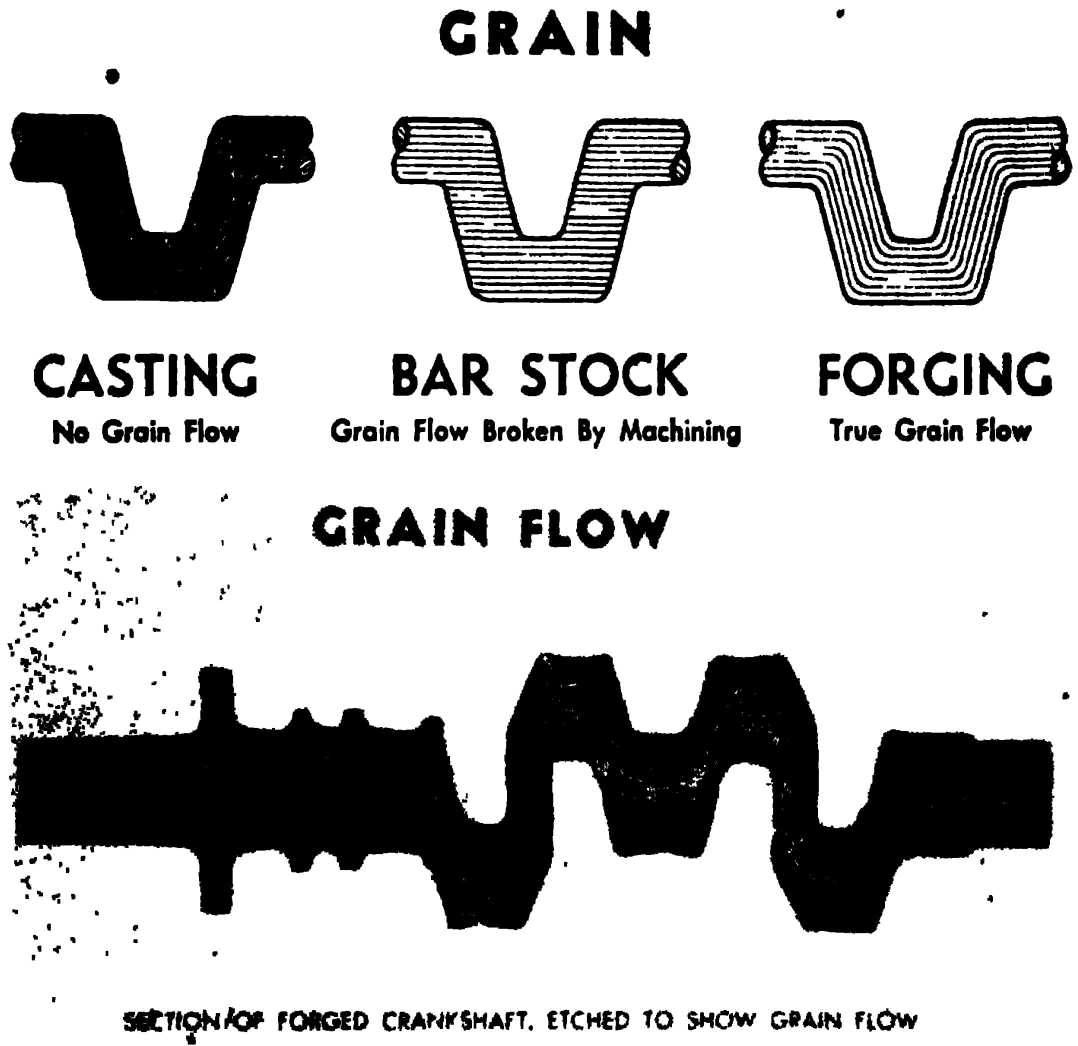

GRAIN
CASTING
No Grain Flow
BAR STOCK
Grain Flow Broken By Machining
FORGING
True Grain Flow
GRAIN FLOW
SECTION OF FORGED CRANKSHAFT, ETCHED TO SHOW GRAIN FLOW

Fig. 1. Comparison of Grain Flow

Courtesy of Chambersburg Engineering Company, Chambersburg, Pa

Concerning factor 3, when a part is forged, the metal is caused to flow, arranging the grain structure of the metal in the position most desirable for the requirements of the part. This grain structure, or grain flow, can be controlled as to density and the slip planes of the grains arranged in such a manner that they will withstand a high instantaneous stress. They will thus be able to take shock loads far exceeding the designed stress allowance. This grain flow is illustrated in Fig. 1, where a comparison is made of identical objects produced by the three manufacturing methods commonly used: casting, machining of bar stock, and forging. The lower illustration depicts a section of a crankshaft that is etched to show the grain flow of the metal.

Concerning factor 4, in comparing a drop-forged part with a casting of the same part, it is found that tolerances relating to size can be held in a forging to much closer limits than in a sand casting of the same size. In forging, no allowance need be made for warpage as must be made in casting. Therefore, much less metal needs to be removed to bring the part to the finished size. It is to be clearly understood, however, that there are many products which may be manufactured by sand-casting methods with considerably greater economy than by drop-forging methods which entail the use of closed-impression dies. These are products which do not require the physical properties obtained through using die-forging methods. The over-all cost of the equipment constituting the machines and the expensive dies used in forging production are avoided when parts are sand cast. If smaller quantities of parts are needed, sand casting is definitely less expensive than forging, since the equipment required in sand casting is relatively inexpensive. This saving in cost of equipment more than offsets the higher labor charges involved in sand casting and the expense arising from the fact that more machine finishing is required.

Concerning factor 5, since the machine finish can be held to such low limits, a drop forging, when compared to bar stock or a sand casting, will have relatively little machining scrap. For example, there is much less waste in the drop-forging flash as compared to the gates and risers of a sand casting. The flash or fin is the metal that is in excess of that required to fill out the final impression in a pair of dies; it moves out as a thin plate around the parting line of the dies.

Concerning factor 6, drop forgings are always made from solid metal bars, thus eliminating the hazard of blow holes often found in castings. Internal flaws in castings will result in rejections to scrap when such defects are discovered during machining. When defects are not discovered in machining or final inspection, unforeseen failures in service may happen.

Inspection of Forging Stock. Careful inspection of the forging stock is the first step in the production of a drop forging in order to insure its quality. In die-forging steel, which is the predominant metal used in the forging industry, the fabricator selects carefully processed, high-grade steel for most forged parts. The expense involved in the design and construction of forging dies will not be justified unless high-grade metal is selected for the product. This metal, particularly steel, is usually rolled in the steel mill to the proper size from high-grade billets.

The steel must conform closely to chemical and physical specifications, as determined by the jobs the finished forging will have to perform. Inspection of the forging steel should reveal an excellent surface on the stock, and an inner structure that is clean and sound. This inspection in many cases includes chemical analysis, surface inspection, hot-acid-etch tests, sulphur prints, shear tests, and physical tests. Of course, the complexity of the chemical and physical tests depends chiefly upon the type of the forged product and the manner in which the product must perform in useful service. For high-grade products, the physical tests include tensile tests, hardness tests, impact tests, and forging tests. The results of these tests are positive, and determine whether or not the steel is to be accepted for forging.

Drop-Forging Hammers. In general, drop-forging machines or hammers used in commercial practice are of either the gravity or steam drop-hammer types. The construction of the machines of both types is basically the same. A machine of either type consists of a rugged frame, stationary anvil, movable ram, source of power, and operating mechanism with controls. The most important additional equipment for each machine consists of the closed-impression dies which impart the required shape to the hammered piece of metal. There are two dies: one is attached to the movable ram, and the other is affixed to the stationary anvil. The hammer, proper, consists of the total mass of movable components, which are the ram, all connecting links, and the upper die. The weight of the hammer which determines the capacity and striking blow of the machine is measured by the total weight of all movable components. The impact blow developed in the drop-forging machine is absorbed, to a large extent, by the machine and its foundation. The latter must be strong and set deep in the ground, especially when large and heavy hammers are used.

The board drop hammer is the most commonly used type of gravity drop-forging machines. The ram carrying the upper impression die is fastened to hardwood boards which pass between sets of rotating rolls in the top of the hammer. Pressure of the rolls against the boards raises the ram and upper die to a predetermined point for release by the operator to strike the forging blow. The striking blow results from the force with which the freely falling ram and upper die meet the fixed lower die. The force of the blow against the fixed lower die depends upon the weight of the freely falling ram and the height to which it is raised. Another kind of gravity-type hammer employs single-acting air or steam cylinders and rods in place of the rolls and boards to raise the ram and upper die. Fig. 2 shows an Erie, type "M," board drop hammer. It is a self-contained machine of all-steel construction driven by a single motor through totally enclosed gearing. Detailed description of this type of equipment will follow later.

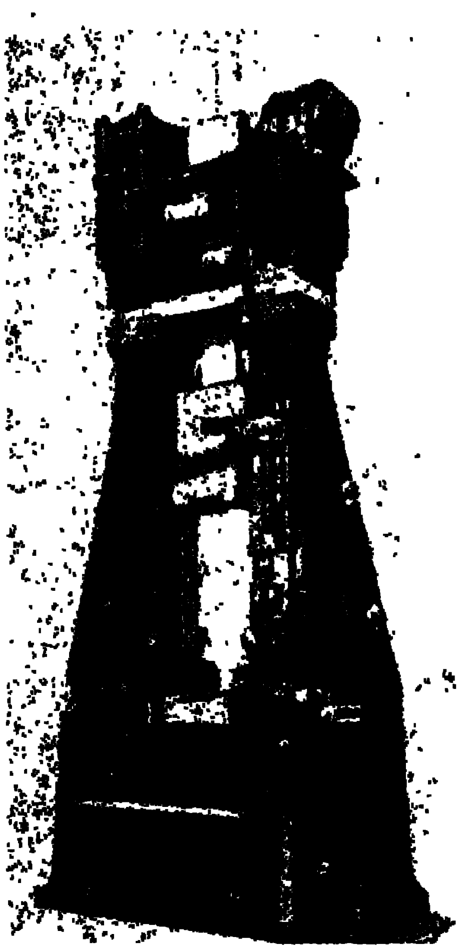


Fig. 2. Board Drop Hammer

Courtesy of Erie Foundry Company, Erie, Pa.

The steam drop hammer is operated by steam and a double-acting cylinder (steam above and below the piston) on the head of the ram to which the upper-impression die is fastened. It enables the operator to raise the ram and die and to increase the force of the forging blow. The force of the blow against the lower fixed die can be controlled by the operator from a light tap to the full-force pound of the steam-driven ram. Operation of a double-acting cylinder in the head of the hammer to raise the ram and die can also be accomplished with compressed air. Air, like steam, can be used to regulate the force of the forging blow. The gravity drop hammer imparts a uniform hammer blow, depending upon the weight of ram and die, while the double-acting steam or air drop hammer can be regulated by the operator to deliver a light tap or a full blow.

Fig. 3 shows a 3,000-pound Erie, steam hammer. The throttle control regulates the opening of the throttle valve for any position of the treadle; thus, the maximum force of the blow and the swing of the ram are controlled when the hammer is idling. The throttle control also shuts off the steam, letting the ram down die to die, when desired, for short intervals. On large hammers in which the work is so heavy that one man is required to manipulate the work itself and a second man to control the hammer, hand-lever operation instead of the foot treadle is available. Detailed description of this type of equipment will follow later.

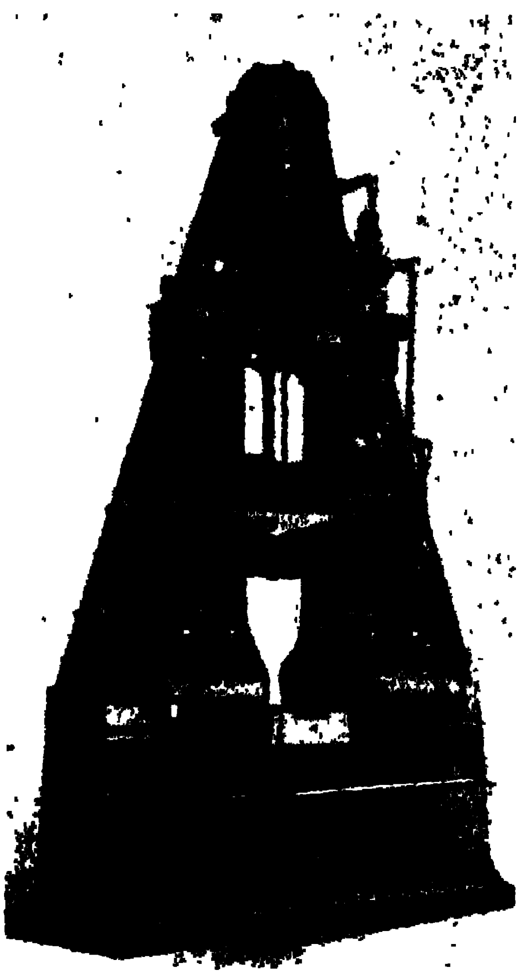


Fig. 3. Steam Hammer

Courtesy of Erie Foundry Company, Erie, Pa.

Closed-Impression Dies. The dies for either the board or steam hammers are constructed from a high-grade carbon or alloy steel furnished in blocks of appropriate size, thus providing ample metal for the machining to be done. The surfaces for the blocks are machined square, and the impressions are laid out on the die faces, after which the die contours are properly machined, the dies are heat treated, and in many cases finished to size by grinding and polishing. The number of impressions (cavities) which may be sunk in a set of die blocks is indicated by the shape and size of the forging and the production (number of forged pieces) anticipated. Fig. 4 shows the operation of drop forging a crankshaft with closed-impression dies.

A pair of dies is needed to perform the operation—one for the anvil and the other for the ram. The dies are made to the shape required on special die-sinking machines and are ready for use after being heat treated and ground. Before being forged, the steel is heated to the correct forging temperature, which is about 2200° F., and then is worked between the dies in the various die impressions. The number of impressions or steps in the dies through which the heated metal is successively worked varies and depends upon the shape of the forged piece. Fig. 5 shows the impressions or steps in one of a pair of typical dies for a connecting-rod forging.

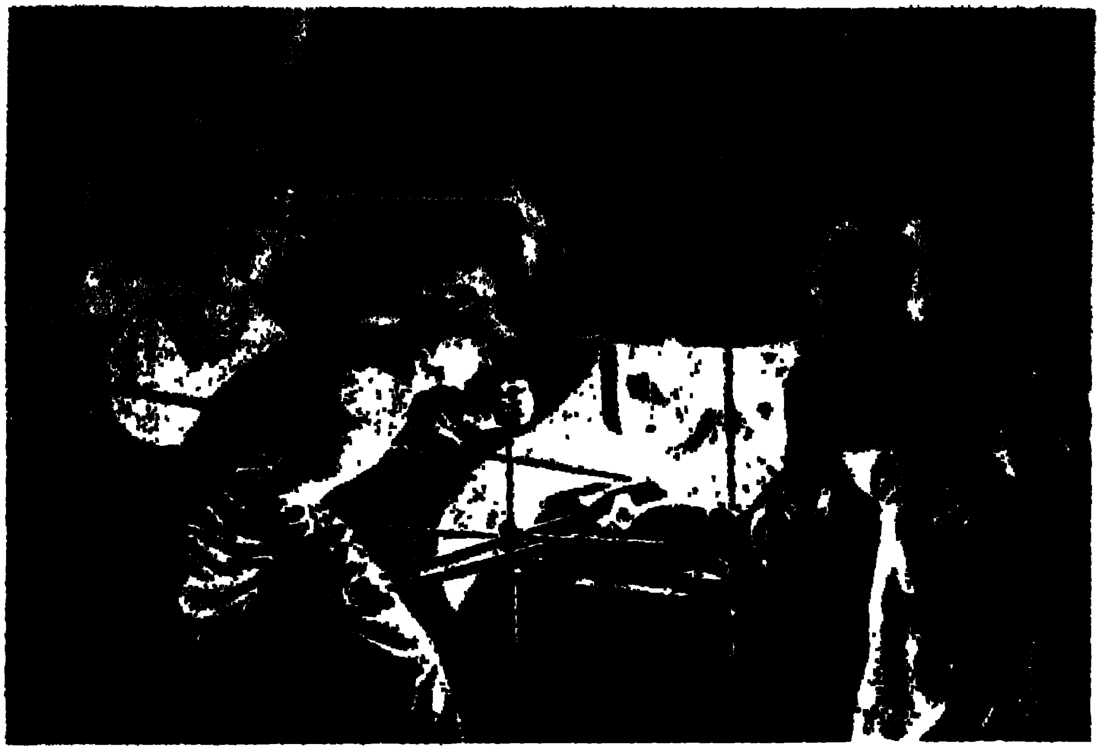


Fig. 4. Forging with Closed-Impression Dies
Courtesy of Drop Forging Association, Cleveland, Ohio

The first impressions of the die shown in Fig. 5, in which the heated steel is worked, are marked *swedger* and *edger*. These impressions produce only a rough and approximate shape of the part. This first rough operation is called the *breakdown*. The next operation consists of working the part in the impression marked *blocker*, in which the shape is developed. The operation that follows is performed in the *finisher*, where the part receives its final shaping. The excess metal is squeezed out into the cavity marked *gutter*. This excess, called the *flash*, is trimmed off in a mechanical press by dies of the correct shape. Trimming of the flash is done after the forging has cooled to room temperature. However, trimming may be done while the forging is hot if its sections are heavy enough to prevent distortion of the metal during the trimming operation.

Successive operations that illustrate the alteration in shape that occurs in the forming of a typical drop-forged part, such as a connecting rod, are shown in Fig. 6.

In this figure, *A* shows the bar cut to length in preparation for the initial forging operation, and *B* shows the pair of closed-impression die blocks designed for the correct shaping of the forged product. Preliminary hot working that proportions the metal is shown at *C;* a blocking operation that shapes the connecting rod into its first definite form is shown at *D;* and a finishing operation that produces the final shape is shown at *E*. At *F*, the trimmed connecting-rod forging is seen. In forming connecting rods, the trimming operation follows finishing immediately, and is performed in a trimming press. For this operation, special trimmer dies that conform to the shape of the part are used. The centers in both ends are punched out at the same time, and the trimmed part is then ready for proper heat treatment and machining. At the bottom of the figure, a macro-etch cross section of the connecting-rod forging is shown. Hot working of the plastic metal by the forging process, using closed-impression dies, resulted in the grain flow and fiber formation that is shown in the illustration.

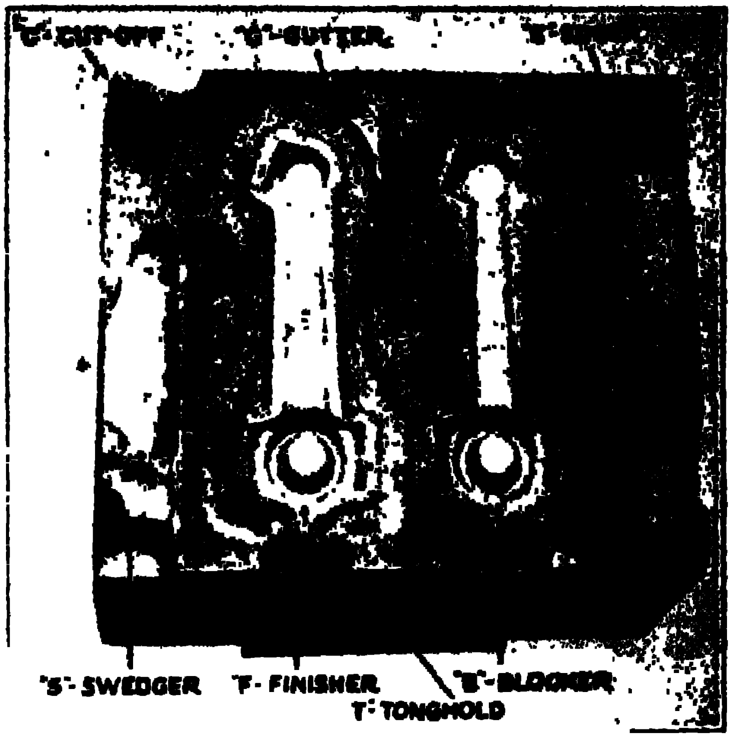


Fig. 5. Typical Die for Connecting-Rod Forging

Courtesy of Interstate Drop Forge Company, Milwaukee, Wis.

The Board Drop Hammer. The major parts and the operation of the board drop hammer briefly explained before are described here in more detail. As previously stated, this type of machine utilizes the force of gravity to deliver the blow. These machines are built in sizes ranging from 100 to 10,000 pounds. These values represent the weights of the falling hammer and all the additional parts attached to it. The board drop hammers are used for forging almost anything from small machine parts to large steam turbines. A typical board-drop hammer is illustrated in Fig. 2 of this chapter.

Delivery of the hammer blows in this type of forging equipment

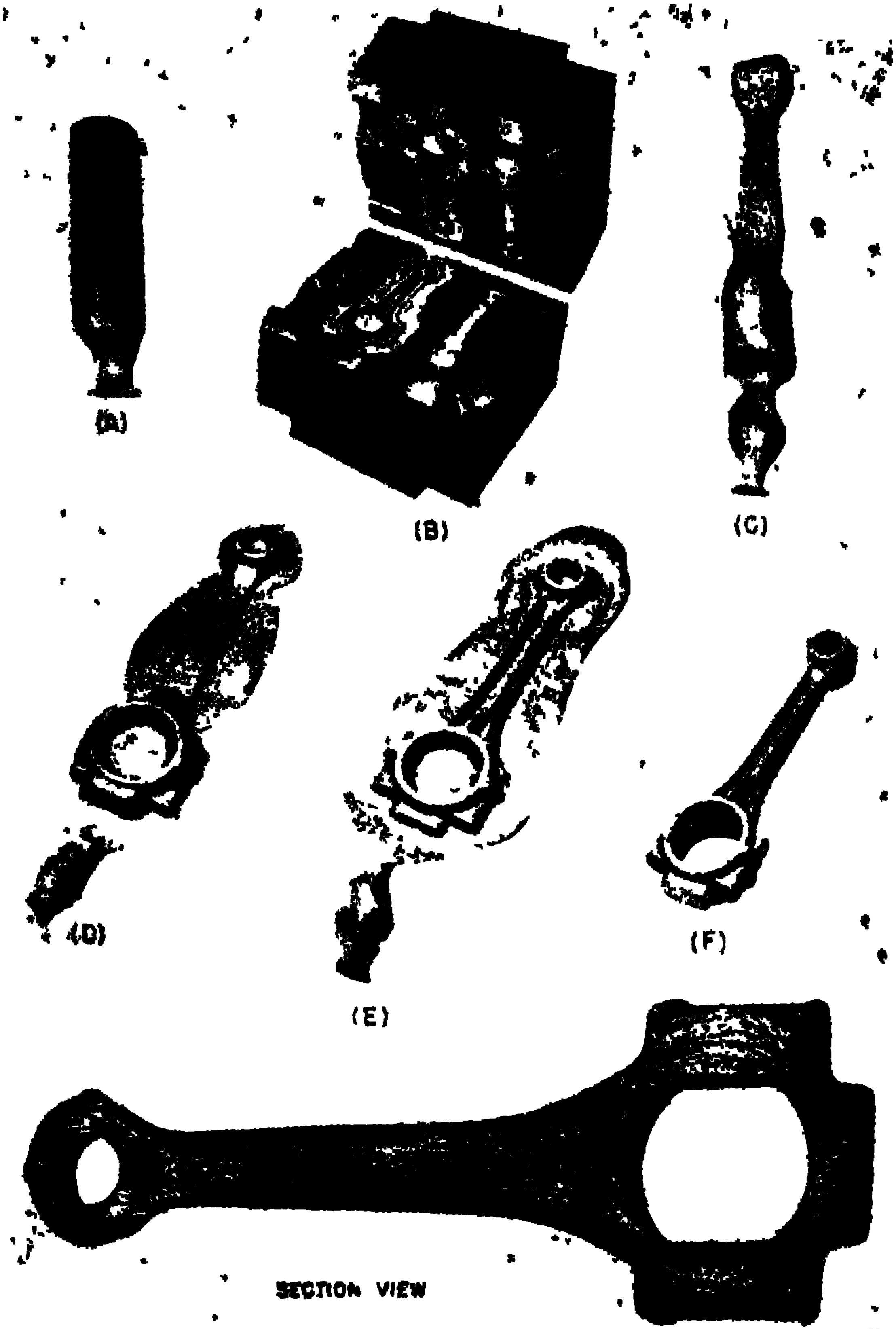


Fig 6 Steps in Forging a Connecting Rod

Courtesy of Drop Forging Association Cleveland Ohio is continuous as long as the operator keeps his foot on the treadle, thus making operation automatic. Several hardwood boards, generally of maple, are attached to the ram. These extend upward be-

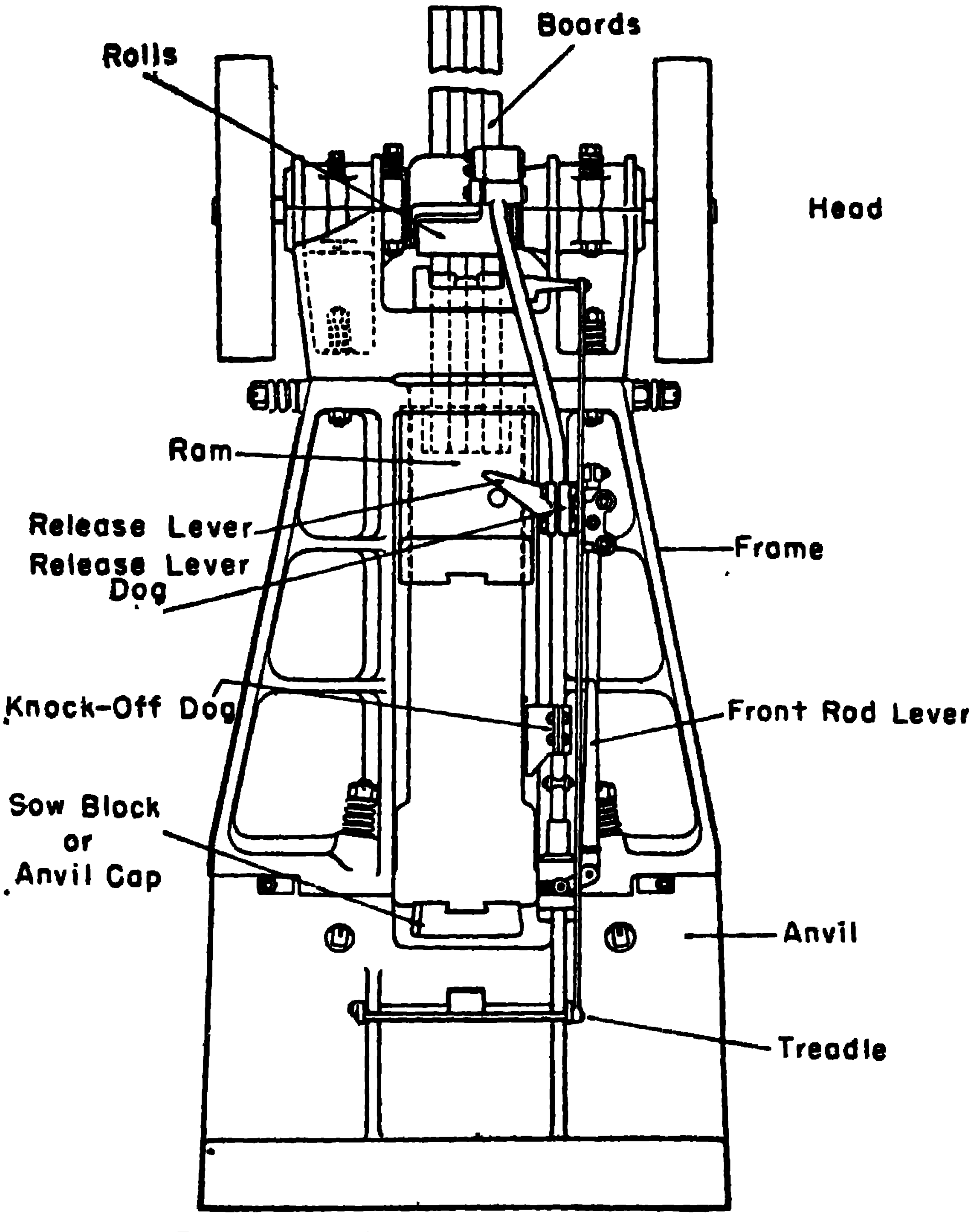


Fig. 7. Parts of a Typical Board Drop Hammer
Courtesy of Chambersburg Engineering Company, Chambersburg, Pa.

tween two or four steel friction rolls which constitute a part of the board-lifting mechanism built into the machine. When the hammer reaches the end of the upward stroke, the rolls are then withdrawn a small amount, and boards and hammer are released. The actuating mechanism controls the height of the fall, and thus makes blows of varying force obtainable. Steel dies are attached to the stationary anvil and to the movable ram by dovetailing each member.

The major parts of a typical board drop hammer are illustrated in Fig. 7, and operation of the hammer is illustrated in Fig. 8. The following paragraphs describe these parts and explain the hammer's operation.

The head containing the mechanism for raising and releasing the ram is placed on top of the frames.

The frames support the head and act as guides for the ram.

The anvil, or base, supports the superstructure and absorbs the forging blow.

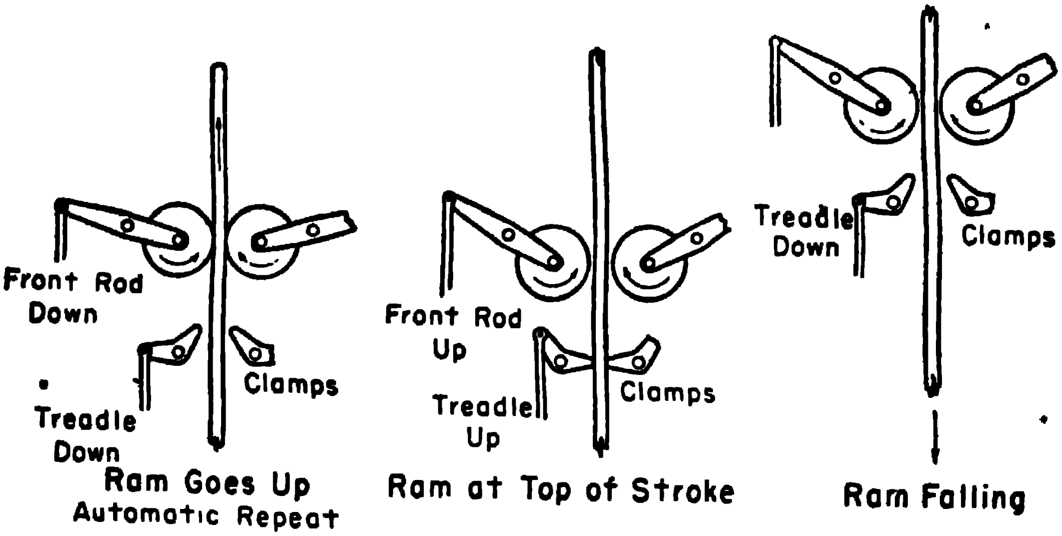


Fig. 8. Operation of Board Drop Hammer

Courtesy of Chambersburg Engineering Company, Chambersburg, Pa.

The sow block, or anvil cap, holds the lower or stationary die.

The ram carries the moving die and, when the boards are released, drops by gravity and delivers the blow.

The boards are fastened to the ram by means of wedges and furnish the means by which the rolls raise the ram to its striking position.

The rolls consist of two cylinders rotating in opposite directions.

These rolls contact the boards to raise the ram, and they release the boards to permit the ram to drop and deliver its blow.

The safety lever is used to make the rolls inoperative, and it functions when the ram is down so that the rolls cannot close on the boards to raise the ram until the safety lever is released.

The treadle is used to release the ram for striking; if held down, it causes the hammer to repeat automatically.

The release lever is actuated by a pin located in the ram. This lever releases the rolls from the boards when the ram has reached the top of its striking position.

The release-lever dog is the part attached to the roll-operating rod through which the release lever actuates the roll mechanism.

The knock-off dog is actuated by the ram at the bottom of the stroke, causing the rolls to engage the boards and return the ram to its striking position.

The three diagrams [Fig. 8] show the action of the rolls and the clamps in operation. The upper left-hand diagram shows that the ram has actuated the knock-off dog, forcing the front rod down and engaging the rolls with the boards. The clamps are not in contact with the boards, as the treadle is down. The diagram at the top right-hand side of the figure indicates that the release lever has been actuated by means of the pin in the ram, thus actuating the release dog and raising the front rod upward, which, in turn, has released the rolls from the boards. When the treadle is up, the clamps hold the boards at the top of the stroke. However, should the treadle be held down, an automatic repeat of the blows of the ram would be obtained.[1]

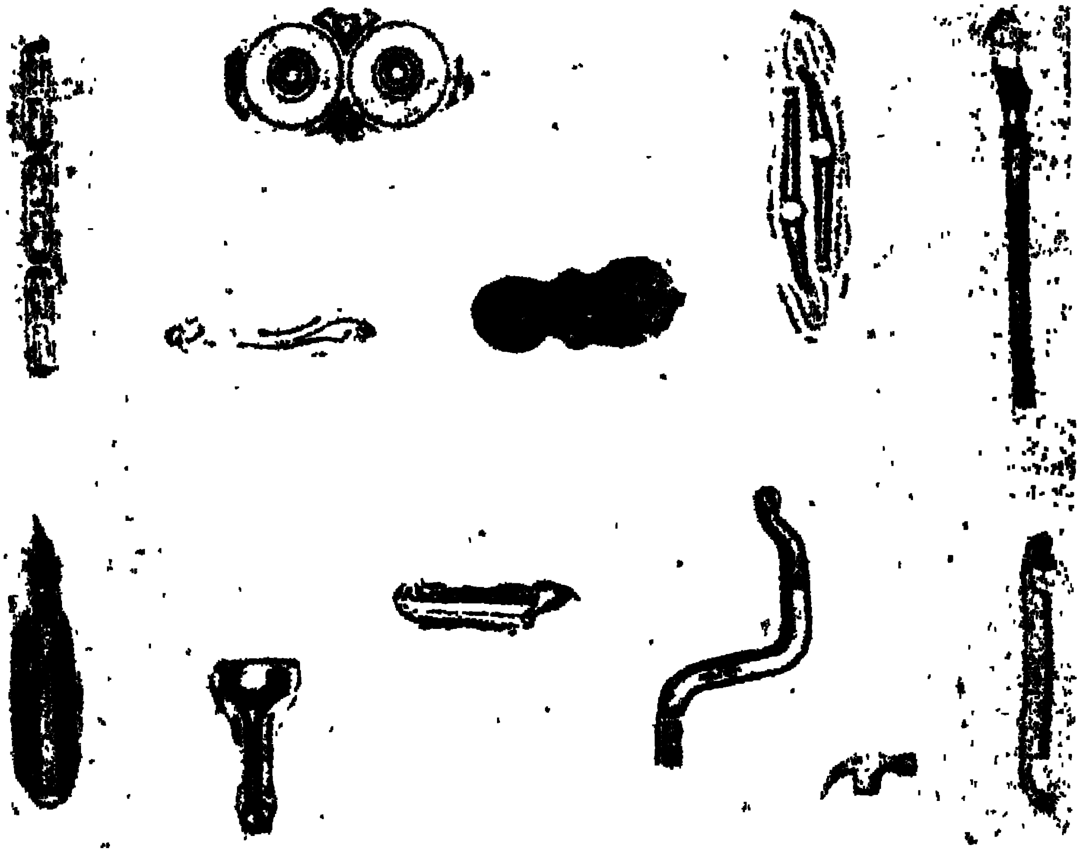


Fig 9. Typical Gravity Drop Forgings

Courtesy of Chambersburg Engineering Company, Chambersburg, Pa

Fig. 9 shows a group of typical gravity drop forgings. An idea of the size and appearance of the type of drop forgings produced by this method may be obtained from the illustration. There are no fixed rules regarding what parts can be made on a gravity-type drop hammer and what parts can be made on a steam drop hammer. An assortment of forgings made on a steam drop hammer is shown in Fig. 13. Naturally, most small hammer forgings of shapes that are not too intricate are made on board drop hammers or other types of gravity drop hammers, while all large forgings and those smaller ones of intricate shape are made on steam drop hammers.

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[1] From *Impact Die Forging*, published by Chambersburg Engineering Company, Chambersburg, Pennsylvania, 1950.

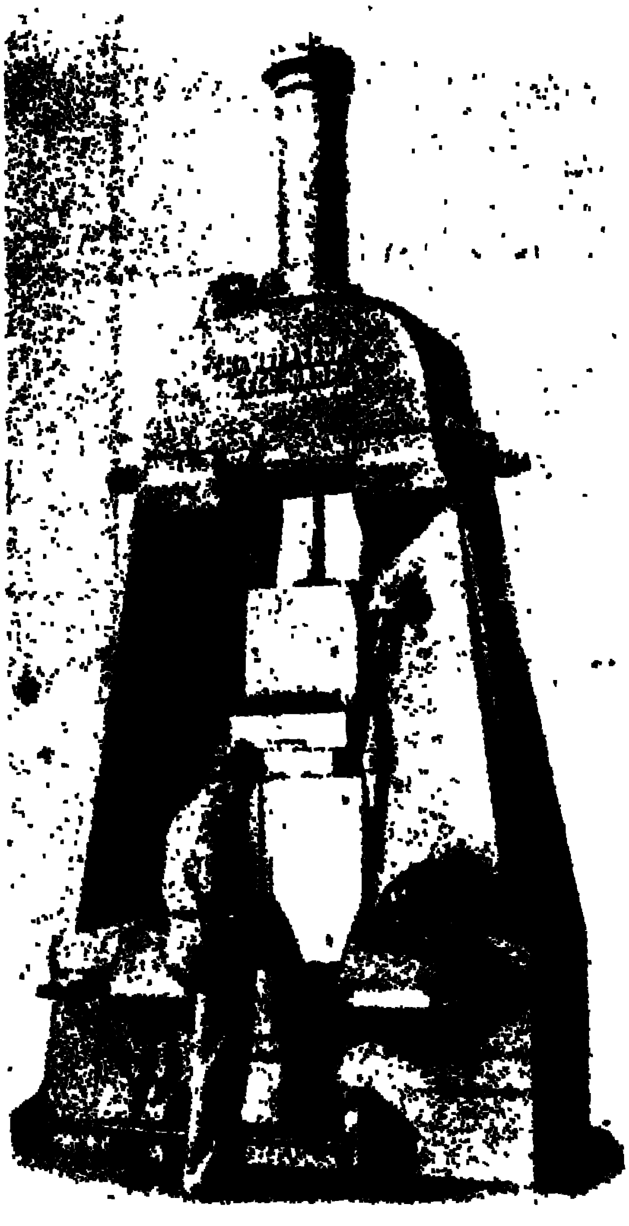

Fig. 10. Ceco-Drop Hammer

Courtesy of Chambersburg Engineering Company, Chambersburg, Pa.

Not all gravity drop hammers are of the board type. As stated before, some gravity-type hammers employ single-acting air or steam cylinders and rods in place of the rolls and boards to raise the ram and die. A new gravity-type drop hammer, called the Ceco-Drop, is shown in Fig. 10. The main feature of this machine is its rapid upstroke, which is accomplished by the employment of air or steam as a lifting medium.

All gravity drop hammers, whether they are of the board type or other types, will come down at the same speed from similar heights, providing there is no obstruction due to friction or back pressure. But on the upward stroke, the speed is limited by the very nature of the lifting-mechanism design. In the case of board hammers, the steel rolls are arranged to lift the maple or other hardwood boards by means of friction. In the case of the hammer shown in Fig. 10, the number of blows in a given time is increased, since an air or steam supply of 100 pounds per square inch affords a mean effective pressure in the cylinder of the machine sufficient to accelerate the speed of the upward stroke of the hammer. These machines are built in sizes ranging from 500 to 5,000 pounds, and are suitable for small-hammer forgings of shapes that are not too intricate.

The Steam Drop Hammer. The major parts and the operation of the steam drop hammer briefly explained before are described here in more detail. A typical steam drop hammer is shown in Fig. 3 of this chapter. This type of machine is similar to that of the steam forging hammer except that the ram must operate in accurate and adjustable guides in order to insure perfect matching of the upper and lower halves of the die. To accomplish this, the hammer frame must be rigidly constructed, alignment of the machine parts must be perfect, and necessary provision for wear of the guides must be made. The ram (with its attached hammer) is lifted by steam, and the force of the blow is controlled by throttling the steam. Operation is very rapid. On many machines, a speed of over 300 blows per minute is obtained. Steam drop hammers range in capacity from 400 to 50,000 pounds.

The major parts of a typical steam drop hammer are illustrated in Fig. 11, and the valve operation of the hammer is illustrated in Fig. 12. The following paragraphs describe these parts and explain the operation of the hammer's valve mechanism.

The head contains the operating valves, the cylinder and safety cover, and is placed on the tie plate at the top of the frames.

The frames, as in the case of the board drop hammer, support the head, guide the ram, and are attached to the anvil.

The anvil supports the superstructure and absorbs the hammer blow.

The anvil base supports the anvil proper and may be in one or many sections, depending upon the size of the hammer and the anvil ratio desired.

The sow block or anvil cap is the part which contains the lower or stationary die.

The ram is the part which delivers the blow and to which is attached the moving die.

The piston rod is attached to the ram and transmits to the ram the additional velocity imparted by the compressed steam or air in the cylinder.

The cylinder delivers the necessary additional velocity to the piston to deliver the striking blow and lifts the ram again to the top of the stroke.

The safety cover contains a safety piston, above which steam is admitted into a cushioning space. But should the working piston, from any cause, go beyond the upper limit of travel, it strikes the safety piston and forces it against the steam cushion. This arrests any further upward movement and prevents damage to the working parts.

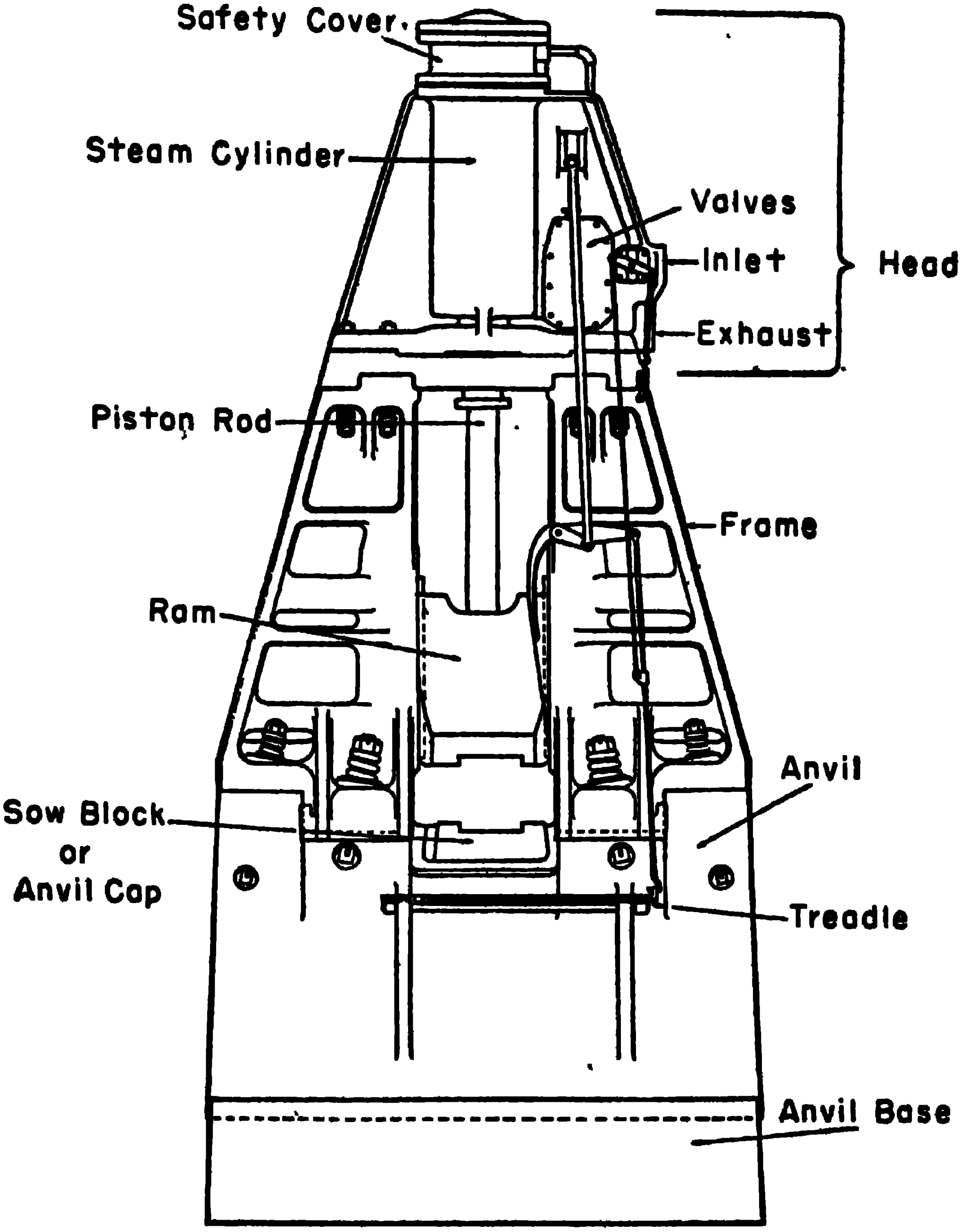

Fig. 11. Parts of a Typical Steam Drop Hammer
Courtesy of Chambersburg Engineering Company, Chambersburg, Pa.

Valves are the operating devices for controlling the steam or air flow into the cylinder, and thereby control the ram.

The treadle is used to deliver the striking blow by controlling the valves. The treadle must be depressed for each blow that is delivered by the steam drop hammer. The magnitude of the blow is determined by the speed and distance the treadle is depressed.

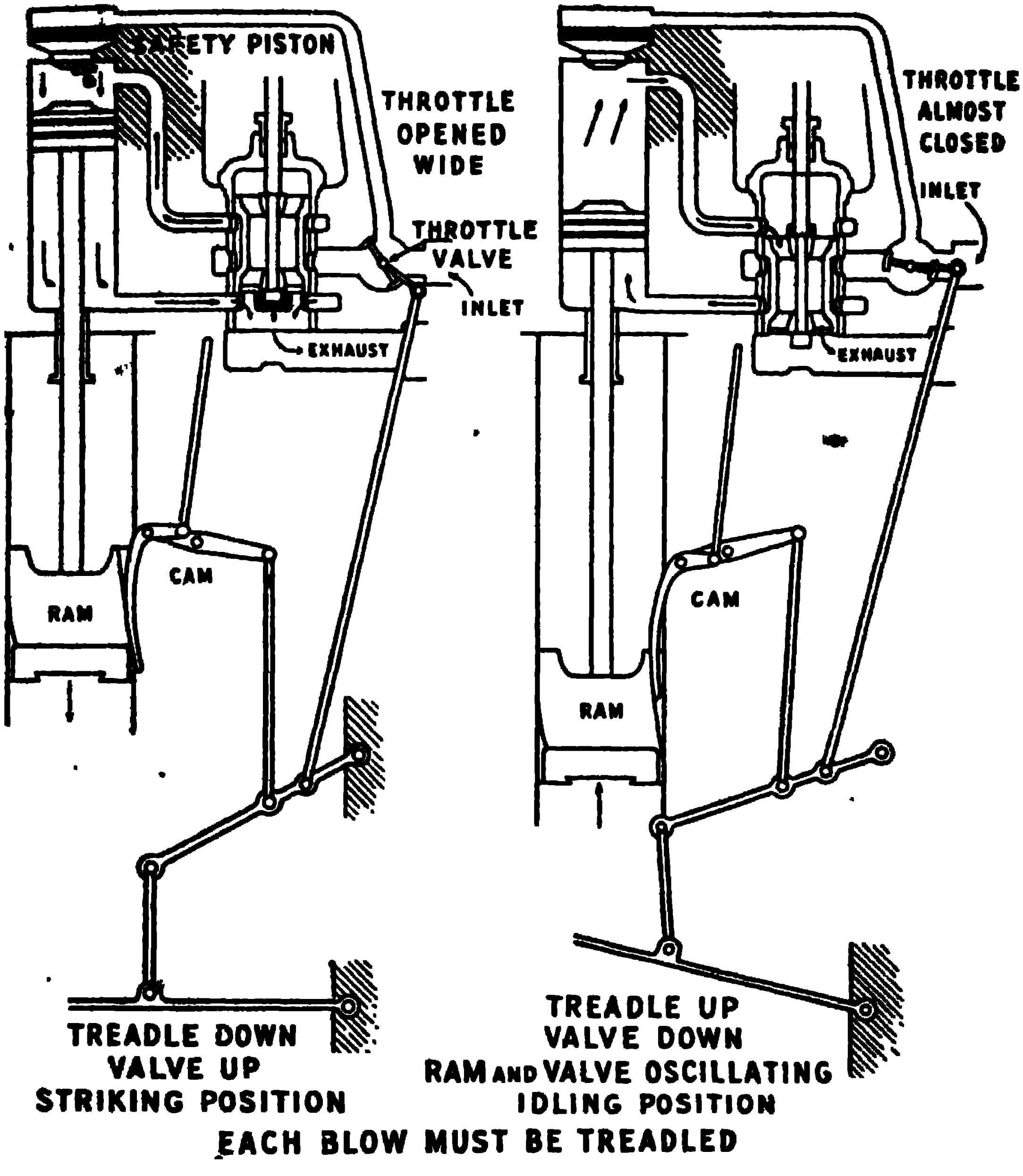

Fig. 12. Valve Operation of a Steam Drop Hammer

Courtesy of Chambersburg Engineering Company, Chambersburg, Pa.

The accompanying diagram [Fig. 12] indicates the location of the valve mechanism when the treadle is down in the striking position. Here, as it can be seen in the diagram, the steam enters through the intake, passing through the wide-open throttle valve to the center of the slide valve, and through the port at its top, causing pressure to be exerted on the top of the piston.

The diagram on the right shows what happens when the treadle is up and the throttle valve almost closed. As can be seen, the slide valve moves downward as soon as the treadle is released, thus allowing the steam to enter through two ports at the bottom of the slide valve, raising the ram to its striking position.

It should be noted that as the ram moves upward it causes a slight movement in the cam which raises the slide valve slightly, thus admitting a small amount of steam to the upper side of the piston and exhausting it from the lower side. As the ram raises still higher, the slide valve moves slightly downward. Such action of the cam, when the treadle is up, causes the ram to oscillate in the idling position, thus keeping a constant flow of steam through the cylinder and preventing the possibility of condensation. It should also be noted that for all valve positions there is a constant flow of steam to the top of the safety piston.[2]

As stated before, the steam drop hammer is suitable for large forgings and those smaller ones that are of an intricate shape.

Energy of the Blow and Forging Effect. The effectiveness of the blow of a hammer depends not only upon the energy of the blow, but also on what percentage of the available energy can be used to deform the metal that is being worked. The principal factors affecting this percentage are the plasticity of the metal, the weight of the upper works of the hammer, and the weight of the anvil. Weight in the frame and cylinder plus the strength and rigidity of these parts hold the reciprocating parts in line. Thus, sidewise deflection is prevented, and all of the available energy is concentrated upon the metal being worked between the dies.

The forging capacity depends upon the weight of the hammer, commonly known as the size of the hammer. Any statement of hammer capacity involves a question of judgment as to the time which can be profitably spent for work of any size. Each case must be considered separately. For example, a small hammer intended for working down bars of small cross section may also be employed for working down larger stock, say a square 6" x 6" billet If the hammer were to be used almost constantly on work requiring 6" x 6" stock, a larger hammer would be much more economical. The production would be higher and the labor cost less. A well-known rule applied in computing the approximate weight of a steam hammer was stated previously as follows: 50 pounds minimum falling weight per square inch of the cross-sectional area of the hammered steel. This, of course, applies to general smith forging or blacksmithing work. It is the average work to be handled at maximum efficiency and not at all the maximum size of the hammer. The weight of the hammer in production drop-forging work depends upon a number of factors and rules of experience which are considered by the manufacturers of production hammers.

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[2] From *Impact Die Forging*, published by Chambersburg Engineering Company, Chambersburg, Pennsylvania, 1950.

The weight of the anvil is important. The lighter the anvil, the more energy of the blow goes into moving it, and the less energy of the blow is absorbed by the work. The *anvil ratio*, which is the ratio of the anvil weight to ram weight, is, therefore, one of the most important factors in forging-hammer design. For average work, an anvil weighing about eight times the weight of the reciprocating parts is generally used. When the metal to be worked is very hard, as for example alloy steels, a larger proportion of the energy in the blow goes into rebound of the ram as it strikes the metal to be worked. A higher anvil ratio, up to about 15 to 1, is then desirable so that more energy is available to shape the work.

No matter what metal is being forged, the loss of energy to the anvil is in inverse ratio to the weight of the anvil. However, unless the metal is difficult to forge, the increase in efficiency is not of enough importance to justify an anvil which is very heavy and out of proportion to the rest of the machine. For example, with a 15-to-1 anvil ratio about 6 per cent of the energy of the blow goes into movement of the anvil. With a 10-to-1 ratio about 9 per cent is lost in the movement of the anvil. Hammers with 15-to-1 anvil ratios which are only 60 per cent efficient (40 per cent of the energy in the blow being lost to the anvil) obviously are costly to operate. The costs of maintaining the anvil and foundation of such a hammer—maintaining them in good condition—are high, owing to the excessively large amount of energy which must be absorbed and dissipated by these parts.

The maximum energy of the blow of a steam hammer can be computed by assuming a mean effective pressure of the steam on the top of the piston at about 80 per cent of the pressure in the line. Multiplying this by the cylinder area gives the steam force that is acting, and the total force acting is obtained by adding this to the weight of the reciprocating parts, which is equal to or greater than the rated size of the hammer. The energy of the blow is obtained by multiplying this force by the length of stroke of the hammer. The average force of the blow can be obtained by dividing this energy of blow by the distance through which the top die moves after striking the work and before coming to rest. This distance is equal to the penetration into the work plus the distance that the anvil moves under the impact of the blow.

For example, in the 1,100-pound steam hammer, the actual falling weight is 1,200 pounds and the cylinder bore *d* equals 10 inches. Assume a mean effective steam pressure *p* equals 80 pounds per square inch. The actual stroke *h* equals 27 inches. Assume that after the impact, the ram continues to move $\frac{1}{8}$ of an inch, owing to penetration of the hammered metal and movement of the anvil. The computation of the force of the blow is as follows:

Steam force $= \frac{\pi d^2}{4} \times p = 0.7854 \times 10^2 \times 80 = 6{,}283$ pounds.

Downward force $= 6{,}283 + 1{,}200 = 7{,}483$ pounds.

Energy of blow $= 7{,}483 \times 27 = 202{,}041$ inch-pounds.

Average force of blow $= \frac{202{,}041}{0.125} = 1{,}616{,}328$ pounds $= 808.16$ tons.[3]

When computing the energy of the blow of a gravity drop hammer, the downward force is equal to the actual falling weight only. All the other computations are similar to those used in steam drop hammers.

Fig. 13 illustrates the difference between the gravity drop of either the board drop hammer or the plain gravity drop hammer and the accelerated drop of the steam drop hammer. It should be noted that the velocity of either type of gravity drop hammer is limited by the free fall of the ram as indicated on the diagram by *h*, while in the steam drop hammer the velocity of the free fall of the ram is accelerated by means of the steam or air used in the cylinder. The normal velocity of the gravity-type drop hammer is approximately 14 feet per second, while the maximum useful velocity of the steam drop hammer is approximately 30 feet per second.[4] The available energy equals $\frac{WV^2}{2g}$, where *W* equals weight of ram, *V* equals ram velocity in feet per second, and *g* equals acceleration due to gravity (32.2 feet per second). It may be seen from the formula that the available energy is greater in a steam drop hammer than in a gravity drop hammer if all other conditions remain the same.

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[3] Numerical values given in this discussion are according to data set forth in Bulleton No. 337 of the Erie Foundry Company, Erie, Pennsylvania.

[4] Numerical values are according to data set forth in *Impact Die Forging*, published by Chambersburg Engineering Company, Chambersburg, Pennsylvania, 1950.

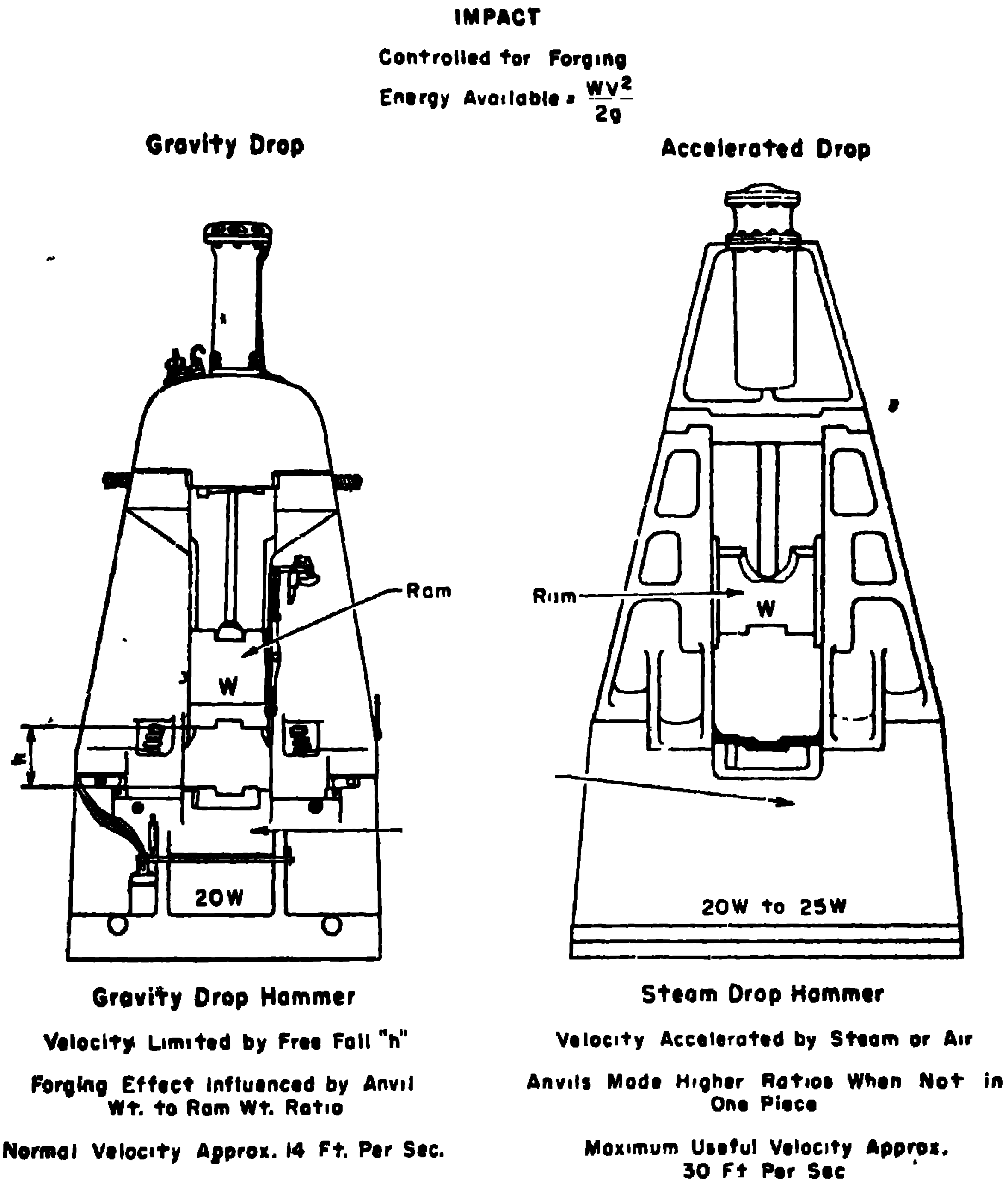
IMPACT
Controlled for Forging
Energy Available = $\frac{wv^2}{2g}$
Gravity Drop
Accelerated Drop
Ram
Ram
W
W
h
20W
20W to 25W
Gravity Drop Hammer
Velocity Limited by Free Fall "h"
Forging Effect Influenced by Anvil Wt. to Ram Wt. Ratio
Normal Velocity Approx. 14 Ft. Per Sec.
Steam Drop Hammer
Velocity Accelerated by Steam or Air
Anvils Made Higher Ratios When Not in One Piece
Maximum Useful Velocity Approx. 30 Ft Per Sec

Fig. 13. Difference between Gravity Drop and Accelerated Drop

Courtesy of Chambersburg Engineering Company Chambersburg Pa

The ratio of anvil weight to ram weight considerably influences the forging effect of the blow, as shown in Fig. 14. The working capacity of a hammer, which is its forging ability, is determined by the weight of the impacting mass, its velocity at impact, the rigidity of the guiding structure and the mass of the anvil which brings the blow to rest. Since the forging effect is in proportion to the square of the impacting velocity, the higher speeds of a hammer are particularly productive. A rigid, heavy, low center of gravity frame is also desirable for good performance.

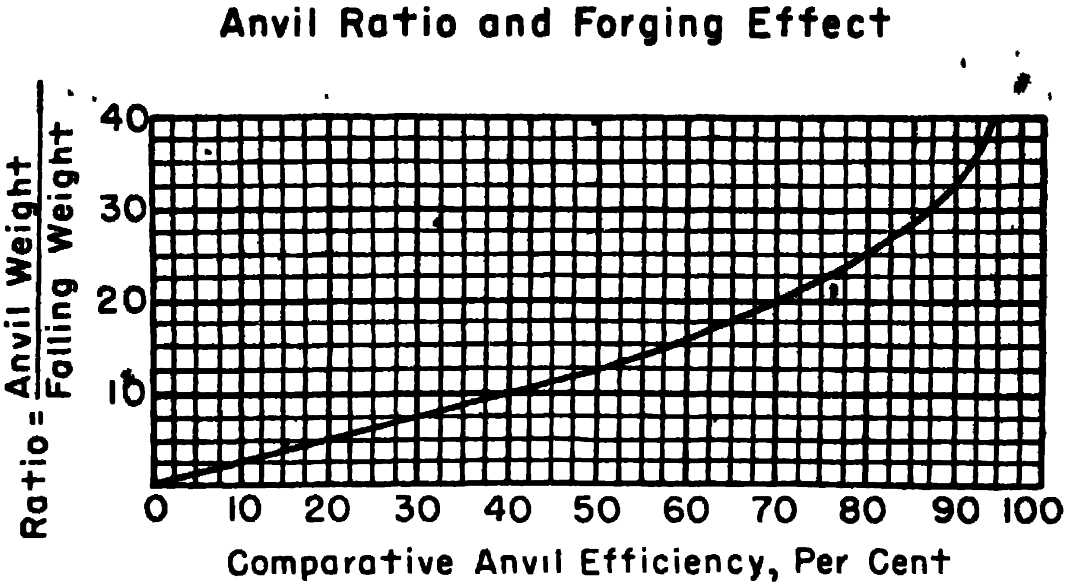

Fig. 14. Anvil Ratio and Forging Effect

Courtesy of Chambersburg Engineering Company, Chambersburg, Pa

Furnaces for Heating Metals before Forging. Proper heating of metals is very important for successful forging; it can be attained if the heating equipment is selected with care. Furnaces of various types are available for heating metals in general and steel in particular. The size, shape, and class of steel to be forged determines the selection of the heating unit, which must be so designed that it will heat the metal correctly and perform satisfactorily when adapted to meet specific conditions. It is rather difficult to design a single furnace and select a fuel which would be fully efficient for a large variety of work. However, in the design of any forging furnace, serious consideration should be given to the matter of providing reasonable working conditions. The furnace should be so located as to permit convenient handling of the work from the furnace to the forging machine. The furnace should also be large enough to allow proper combustion of fuel and uniform distribution of heat in order to provide suitable heating conditions for the metal. Recommendations by furnace builders should be adhered to for best forging practice.

The typical construction of most forging furnaces is illustrated by the three views of Fig. 15. View *A* shows a cross section of a side-fired furnace with baffle to prevent the flame from impinging on the work. View *B* shows a cross section of a direct-fired furnace, where the products of combustion come in contact with the metal being heated. View *C* shows a cross section of a furnace with electric heating coils.

The furnaces should be made of highly refractory material, well insulated. The general run of work to be heated in the furnace determines its length and other dimensions. The hearth in the furnace should slant toward the rear of the structure to permit the slag formed on the hearth to run back and out through a slag hole provided for this purpose. A rectangular hearth, an arch roof, and a door opening in front are characteristics of predominant furnace design. Chiefly firebrick is used to make the furnace, and the thickness of brick should not be less than 9 inches. A strong steel frame is designed to support the brick structure. The burners, if used, should be fastened firmly to the furnace, and the flame entering the furnace should not be allowed to impinge on the steel. This may be accomplished by providing a baffle or other device to protect the steel, as shown at *A* in Fig. 15. In the case of heating bars, the furnaces are built narrow and deep. Wide and shallow furnaces are recommended for work of large cross-sectional areas.

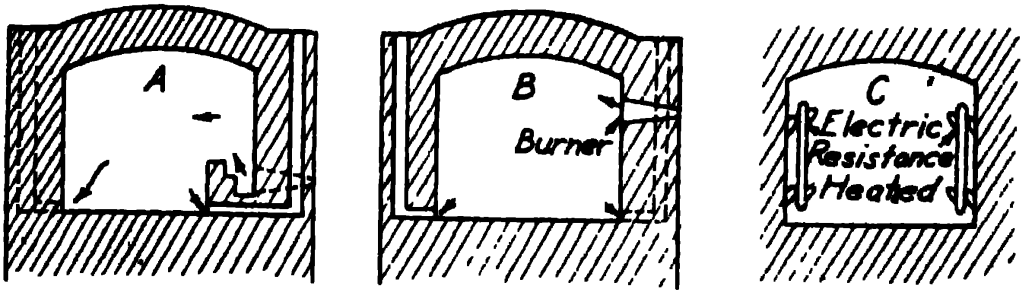

Fig. 15. Construction of Typical Forging Furnaces

Fig. 16 shows a modern type of forging furnace with protecting shield. The furnace is of rigid construction, and is either gas or oil fired. It may be operated economically in heating for forging and welding operations. The protecting shield may be adjusted to protect the operator from the heat and, at the same time, afford him a good view of the material being heated in the furnace. The shield may be air-cooled or water-cooled or lined with a refractory material. All modern forging furnaces are equipped with automatic temperature-control devices, which enable the operators to maintain firing conditions as desired. Among the several advantages of automatic temperature control is the lowering of cost of forging by reducing fuel consumption and by reducing the amount of upkeep attention that is needed to keep the furnace in good condition.

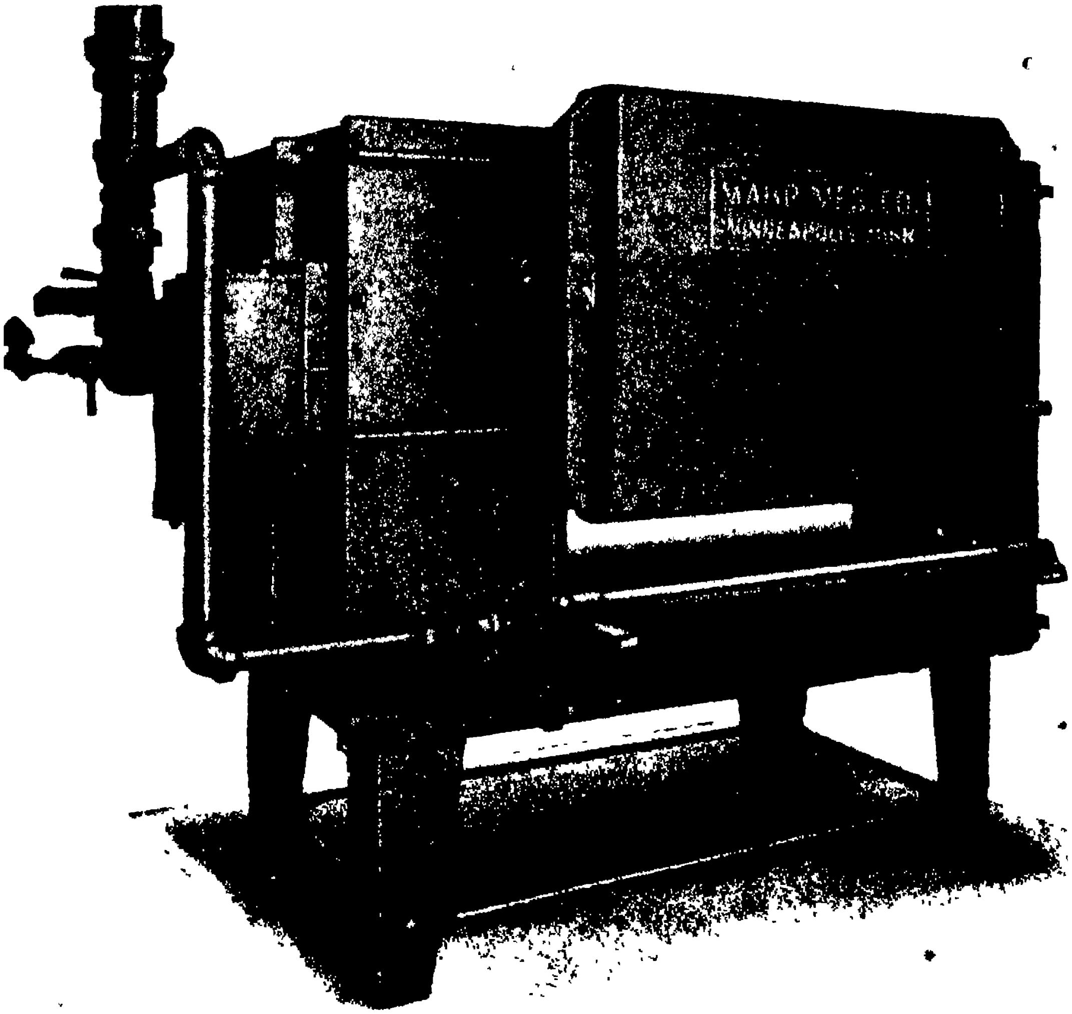

Fig. 16. Slot Type of Forging Furnace with Protecting Shield
Courtesy of Mahr Manufacturing Company, Minneapolis, Minn

Forging shops which handle a large variety of steel sizes and shapes employ the *batch* or *in-and-out* type of furnace, wherein a fairly large quantity of metal may be heated at the same time. However, modern shops handling large tonnages of steel are using *automatic-conveyer* or *pusher* furnaces with considerable success. In the *chain-conveyer* furnace, the chain carries the metal through the furnace from the charging end to the discharging end. Fig. 17 shows an electrically heated, chain-slat-conveyer furnace that is used for heating aluminum billets prior to forging. The metal is carried through to the discharging end of the furnace by means of the moving slats. The discharging end of the furnace is located conveniently near the forging machine. In some installations of this type, the furnace is located above floor level, with the discharge chute arranged to deliver heated billets automatically to the operators of the forging machine.

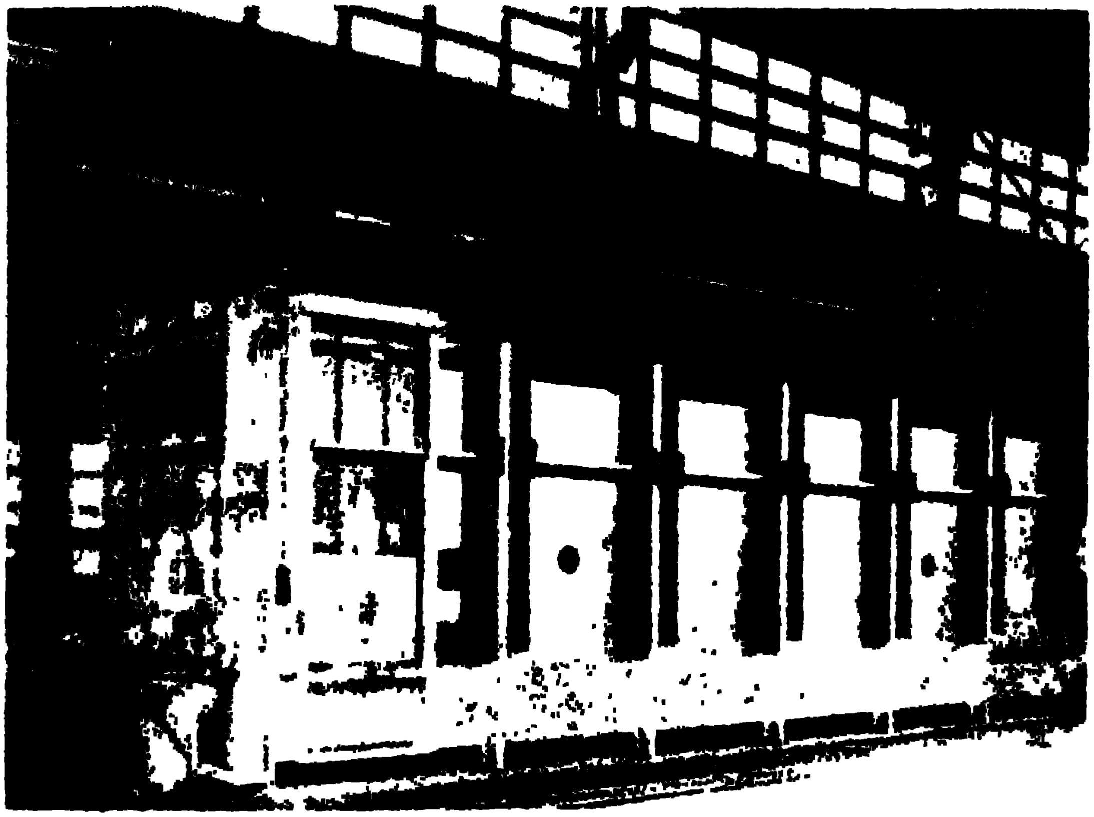

Fig. 17. Electrically Heated Chain-Conveyer Furnace

Courtesy of The Electric Furnace Company, Salem, Ohio

Fig. 18 shows another continuous-type furnace, which is automatically controlled. The hearth of this furnace rotates. The installation includes automatic temperature-control devices, which keep the furnace at any desired temperature and prevents overheating of the metal, even if a delay occurs, causing the metal to remain in the furnace longer than normally required. The operation of this furnace consists of placing the metal on the hearth by the operator, after which it is carried completely around the circle and heated. Finally, it is removed by the operator and placed at a point convenient to the forging machine. Successful operation of automatic heating equipment is substantially dependent upon the quantity and upon the uniformity of the shape and size of metal to be forged

Electric heating for forging operations is rapidly increasing, especially for nonferrous metals. The electric-resistance furnaces are not very succesful for heating steel, because they operate at lower temperatures than fuel-fired furnaces, and because they entail a higher cost-per-pound of steel heated. Nevertheless, electric-resistance heating has many advantages for nonferrous metals and special forging applications. The operation of these furnaces consists in passing an electric current through the metal to be heated. The resistance of the metal to the electric current heats the metal. The only loss of heat is by radiation. This method of heating cannot heat steel rapidly since the forging temperature of steel is quite high, about 2200° F. The core of the metal heats first, followed by the remaining stock. Uniform heating of the metal, therefore, results. The maximum temperature of the metal may be automatically controlled by *photoelectric controllers*, commonly known as *electric eyes*, posi-

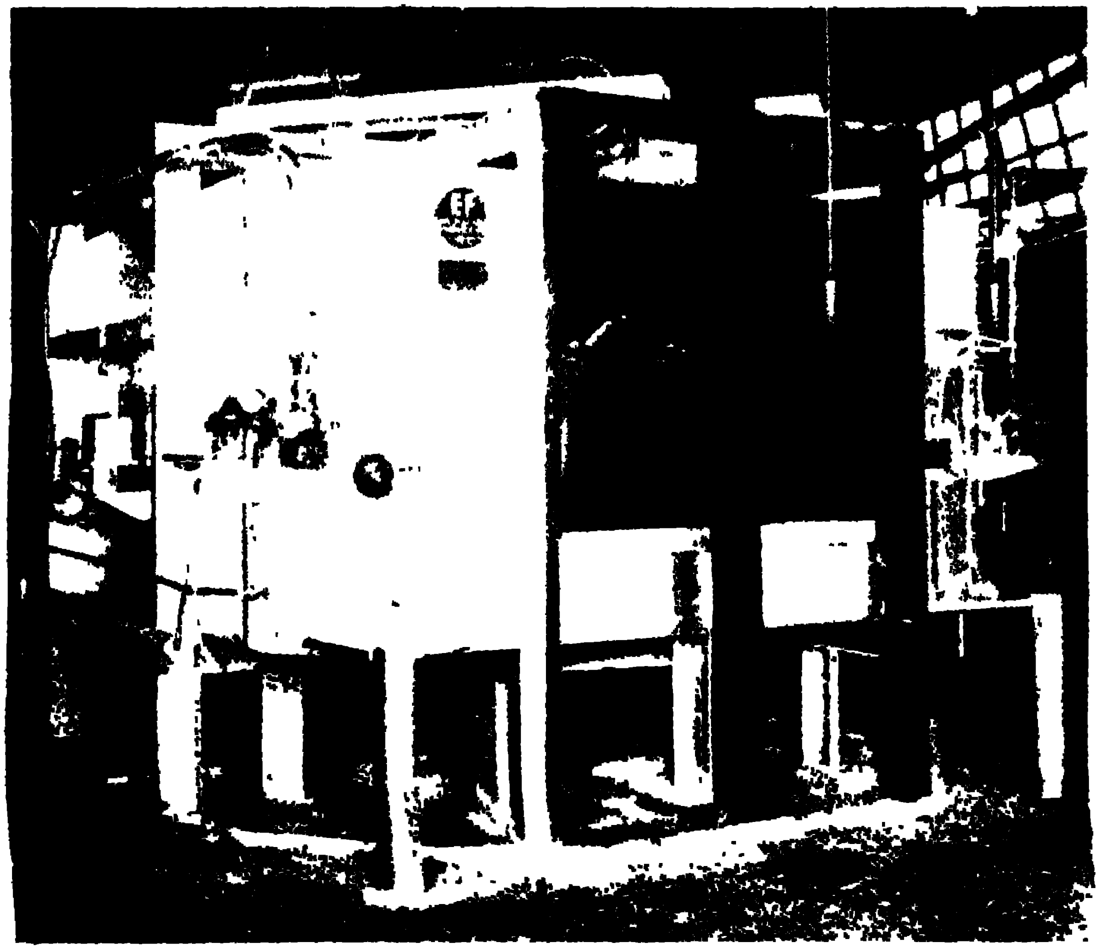

Fig. 18. Oil-Fired Continuous Rotary Hearth Furnace

Courtesy of The Electric Furnace Company Salem, Ohio tioned properly with respect to the work and contacts of the heating unit. Instant adjustments of temperatures are possible in this type of heating equipment, and all danger of either overheating or underheating the metal is avoided. Fig. 19 shows an electric-resistance heater, which has a capacity to heat metal from ⅝ to 1½ inches in diameter, and from 1 to 24 inches in length.

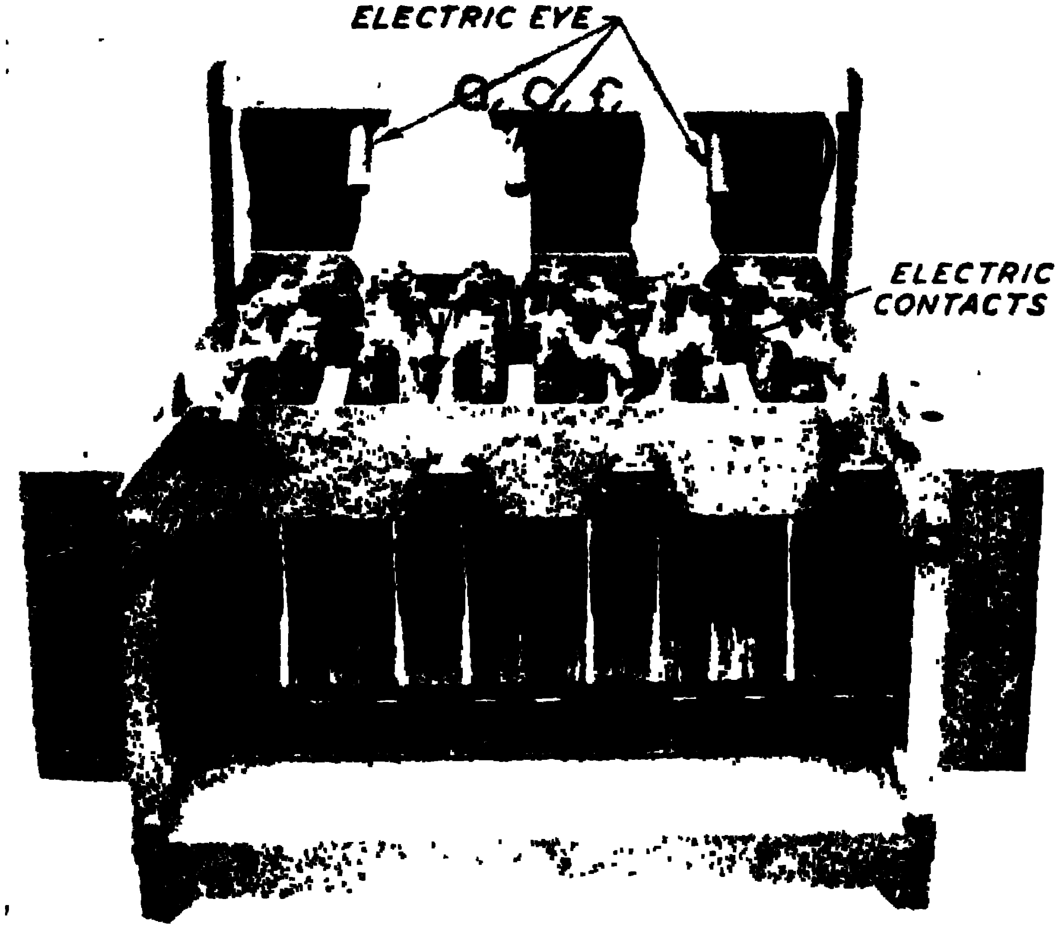

Fig. 19. Electric Resistance Heater
Courtesy of American Car and Foundry Company, Chicago, Ill.

In recent years, high-frequency induction furnaces have been used successfully for the heating of metals, particularly steel, in preparation for numerous hot-forging operations. The heating unit of the induction furnace consists of a high-frequency induction heating coil and heater-control panel. The heating unit is usually designed to meet particular requirements. This method of heating metals has many advantages, among which the following are the most important: rapid heating, local heating only if required, i.e., heating of parts of the metal, and heating without scale forming on the surface of the metal. Small steel sections, solid or hollow, may be heated locally to proper forging temperatures in less than one minute. Larger sections require a somewhat longer time for proper heating.

Supplementary Operations. Metal for forging must first be sheared or sawed to the required length, and then heated to the correct forging temperature in well-selected furnaces recommended by furnace builders. The correct forging temperature of steel is about 2200° F. The importance of correct heating cannot be overemphasized. Appropriate shearing or sawing equipment of simple design is used in the shop for preparing the stock to the required length.

Trimming presses are needed in the forge shop to remove the flash around the edge of a drop forging. Flash is the extra-thin metal which is squeezed out by the impact of pressure of the hammer blow when the hot plastic metal completely fills the confining die cavities. Flash is sheared off in a set of trimmer dies. The trimmer press is located near the hammers for hot trimming the parts as they are forged. Cold trimming is also performed, especially on small parts forged two or more at a time from a single piece of metal. *Punching operations*, if required, may also be carried out simultaneously with the trimming.

Most carbon and alloy steels are heat treated to bring out in the exact degree the desirable physical properties that are already inherent in them. Controlled heat treatment of forgings is important in order to make them most useful for rigid service. Proper equipment, timing, and instrumentation are the chief prerequisites for successful heat treatment of forged parts. The heat-treatment process will be explained in detail later in this text.

Materials-Handling Equipment. Materials-handling in the modern production forge shop has reached an important phase. Many supplementary operations are attendant upon forging. There is a need in the forge shop for various types of handling equipment, which are needed not only for lifting the raw stock and bringing it to the furnace and then to the forging machine, but also for moving and shifting the forged material about for additional operations, such as trimming, heat treatment, coining, sizing, restriking, etc. Coining, sizing, and restriking operations are carried out for the purpose of obtaining forgings of close-dimensional tolerances.

The type of handling equipment needed depends upon the kind of forging work done in the shop—whether it is open-die or closed-impression-die work, or many other kinds of forging work which is practiced in modern production. The equipment is mainly of two types: hand-operated devices and power-operated devices. The hand-operated equipment includes various hand trucks, wheelbarrows, buggies, hoists, cranes, and overhead carriers. The power-operated equipment includes various lift trucks, tractors, hoists, cranes, overhead carriers, conveyers, and stock manipulators.

Where heavy work is to be handled, it is necessary to have some suitable means of conveying the work from one part of the shop to another. Also, various quantities of steel that are kept at the forge shop in the steel storage yard until prepared for forging operations require proper conveying equipment. Such material is moved by means of cranes of two general types: the *traveling crane* and the *jib crane*. The traveling crane generally runs on an overhead track from one end of the shop to the other. The jib crane is mostly employed for handling work under the forging hammers. It consists of an arm or boom swinging around a post and having a convenient arrangement for raising and lowering the work. Heavy work is often suspended from the crane by its center, if possible, in such a way that it nearly balances. An endless chain is usually employed to enable easy rolling and swinging of the suspended work from side to side.

REVIEW QUESTIONS

1. Explain briefly the essentials of the drop-forging process.
2. Describe the operation of the Ceco-Drop hammer.
3. What are the advantages of drop-forged products?
4. Describe briefly the two types of drop-forging hammers.
5. What determines the number of impressions in drop-forging dies?
6. What is the range of sizes of board drop hammers?
7. What is the range of sizes of steam drop hammers?
8. What are closed-impression dies?
9. Discuss the energy of the blow and forging effect of a hammer
10. What is meant by forging capacity, and how does it depend upon the weight of a hammer?
11. Discuss the weight of a hammer, the weight of an anvil, and anvil ratio.
12. The actual falling weight of a steam hammer is 1,600 lb., and the cylinder bore is 12″ (diameter). Assume a mean effective steam pressure of 80 lb. per sq. in. The actual stroke is 30″. Also assume that after the impact, the ram continues to move .140″ due to penetration of the hammered metal and movement of the anvil. Compute the average force of blow in tons.

13. Prove that the available energy in a steam drop hammer is greater than the available energy in a board drop hammer, if all other conditions remain the same.

14. What are the chief requirements that good forging furnaces must meet?

15. Describe briefly the construction of a modern forging furnace designed with protecting shield.

16. Describe the operation of the automatic-conveyer or pusher-type forging furnace.

17. Discuss the advantages of electric heating for forging operations.

18. What is the function of trimming presses in a forge shop?

19. Name the supplementary operations which follow the operation of impact forging.

20. What is the purpose of heat treatment of forgings?

21. Name some of the materials-handling equipment that is used in modern production forge shops.

CHAPTER VI

Typical Examples of Impact-Die Forging

Forging a Large Connecting Rod for a Diesel Engine. A typical example of forging a common connecting rod with closed-impression dies by the drop-forging process was illustrated and described in Fig. 6 of Chapter V. The various steps followed in forging this part have been fuly explained and, therefore, there is no need of repeating the description. However, other illustrative examples will be treated in this chapter to demonstrate how forging with closed-impression dies develops maximum metal quality. As previously explained, this process is not recommended as a replacement for other manufacturing processes, unless the product in question must meet rigid requirements in service. Forging is not always more economical than other processes capable of producing the required part.

A forging for a diesel-engine connecting rod is over 3 feet long and weighs about 85 pounds. In contrast, an average automotive-engine connecting rod, shown in Fig. 6 of Chapter V, is about 14 inches long and weighs approximately 4 pounds. The very nature of the diesel-engine rod is such that only slight variations in its weight are permitted, because perfect balance is demanded when the rod is assembled in an engine. The following illustrations show the production forging equipment and the various steps required to produce this part.

The actual mechanical operation of forging this part begins with selection of a rough steel billet of square cross-section measuring $4\frac{13}{16}'' \times 4\frac{13}{16}'' \times 18\frac{1}{2}''$. This billet must be heated to the correct forging temperature, which is about 2200° F. for steel, before being worked into the form of the required connecting rod which is 38 inches in length. The heating of the billet may be considered as the first operation. It is followed by a number of mechanical working operations which are carried out with the aid of forging presses or hammers and suitable dies. Fig. 1 shows the metal stock from which the required part is made.

Fig 1 Metal Stock
Courtesy of Drop Forging Association Cleveland Ohio

The first mechanical operation is the forming of a projection at the end of the forging, called the *tonghold*. This projection allows the rough stock to be gripped by the operator with a pair of tongs. The tonghold is formed by striking the end of the stock with the upper die. After the tonghold is formed, the heated stock is placed in the rolling impression on the die. The stock is rolled between successive blows of the hammer, and this action elongates the metal from one end of the stock to form the portion which will be the arm section of the connecting rod. The rolling operation is shown in Fig. 2. The dies shown in the figure are the preforming and blocking dies. They are used for a series of operations as shown in the following illustrations.

Several sets of dies are required to complete this forging. The dies shown in Fig. 2 contain the impressions not only for forming the completed part, but also for elongating the stock, and for rolling and blocking it. When dies are made, the impressions are first laid out on a set of rough die blocks. Then follows the operation of die sinking, which consists of, first, rough milling the impressions in the die blocks and, then, of precise-finish milling combined with bench work.

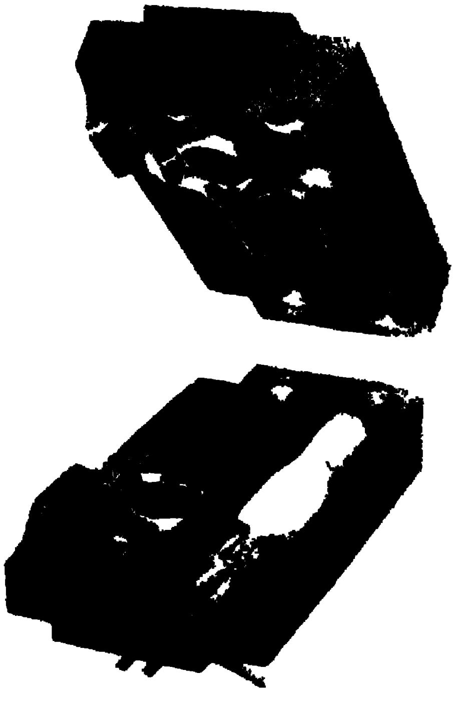

Fig. 2. Rolling Operation
Courtesy of Drop Forging Association, Cleveland, Ohio

Fig. 3 shows the fullering operation, the purpose of which is to reduce the cross-section area of that portion of the metal stock between the large end boss and the piston end of the connecting rod.

It is done by striking the heated metal, which is placed between the fullering cavities of the upper and lower dies. This operation forces the metal to move outward and away from the center of the stock. The forging illustrated in this example shows how the metal is reduced by the fullering operation to preform the narrow rod section without changing the distribution of metal for the other sections of the forging.

Fig. 4 shows the operation of flattening the large end boss, which is accomplished by striking the stock on the flat surface of the die before the blocking operation. The purpose of this operation is to force the stock to conform more closely to the blocking impression. The stock formed at this stage begins to resemble the approximate contour of the required forging.

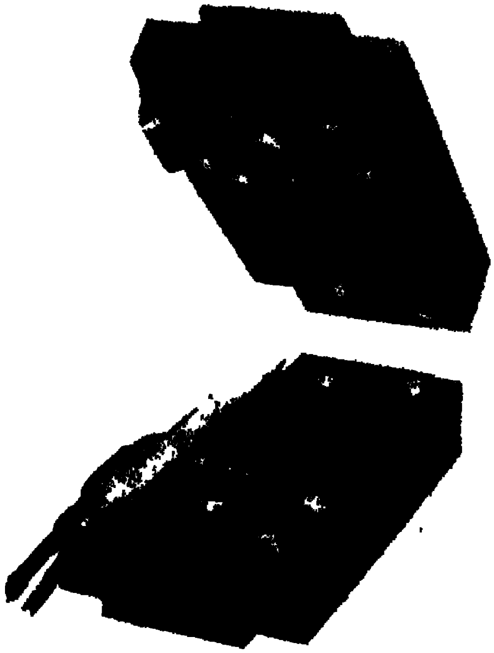

Fig. 3. Fullering Operation
Courtesy of Drop Forging Association, Cleveland, Ohio

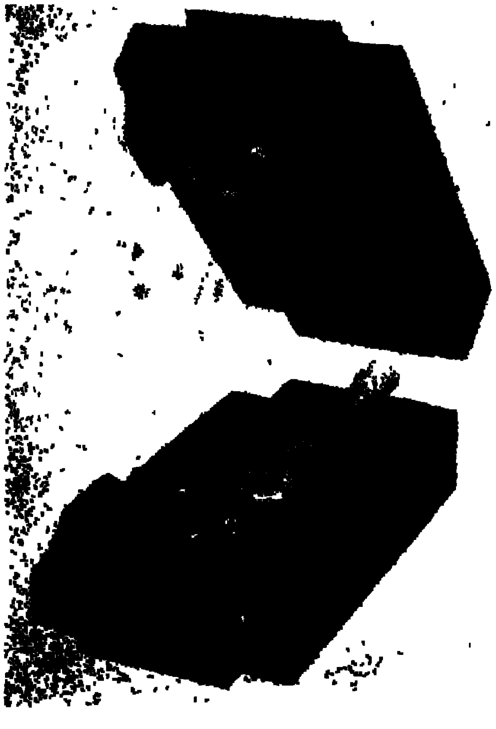

Fig. 4. Flattening Operation
Courtesy of Drop Forging Association, Cleveland, Ohio

Fig. 5 illustrates the action of the second rolling operation. The purpose of this operation is to reduce and gather the forging stock to the proper proportion required for each section of the connecting rod and to smooth out irregular surfaces. The distribution of metal obtained by this operation makes it possible to form the stock properly in the blocking impression which follows immediately after this operation. The metal will then reach the sidewalls of the die impression simultaneously throughout its entire perimeter.

Fig. 6 shows the blocking operation which forms the connecting

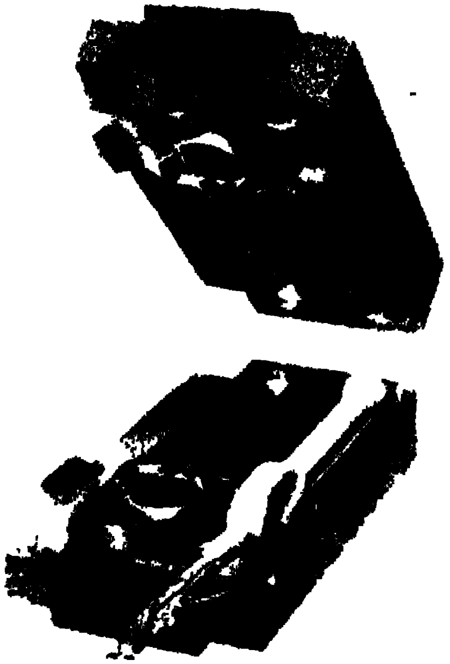

Fig. 5. Second Rolling Operation

of Drop Forging Association
Cleveland, Ohio

rod into its first definite shape. The operation consists of several successive blows of the hammer. The hot metal is forced to flow into the die impressions and completely fill them at every section of the rod. This hot working of the metal in the dies produces a grain flow which gives real strength to the required forging.

All metals, particularly steel, are crystalline in structure when they are in a solid state. The crystalline grains which make up the substance of the metal will flow when the heated metal is forged. This grain flow is uninterrupted when the forging is carried out with the aid of closed-impression dies, thus resulting in a tough and strong finished metal product

The blocking operation also imparts necessary strength to the crank end of the rod—strength which can resist the excessive shock and strain resulting from each turn of the crank when the parts are in service.

The operation shown in Fig. 6 completes the preforming operations on the connecting rod as performed in the first set of dies. The unformed metal around the edge of the forging is the flash which is forced away from the die impressions after the rod has been formed by successive blows of the hammer. In successful forging, care is taken to carry out properly all of the prelimi-

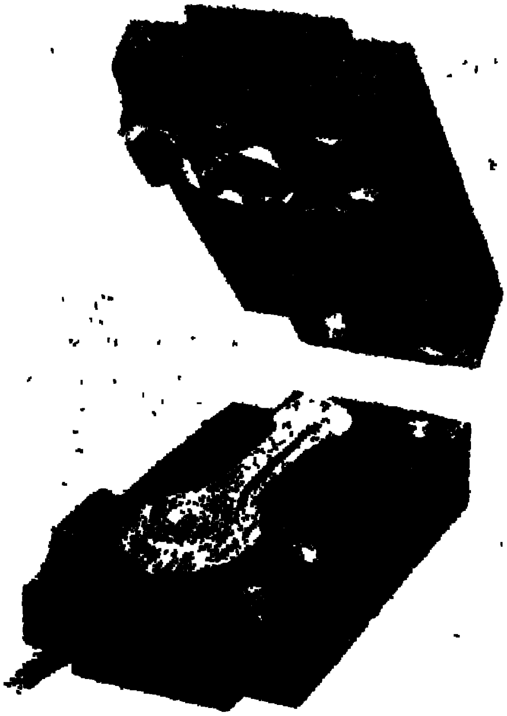

Fig. 6. Blocking Operation

Courtesy of Drop Forging Association
Cleveland, Ohio

nary operations, thus insuring a satisfactory finished product. The finishing dies contain impressions which are an exact counterpart of the finished forging. The product, therefore, is accurate in weight and dimensions.

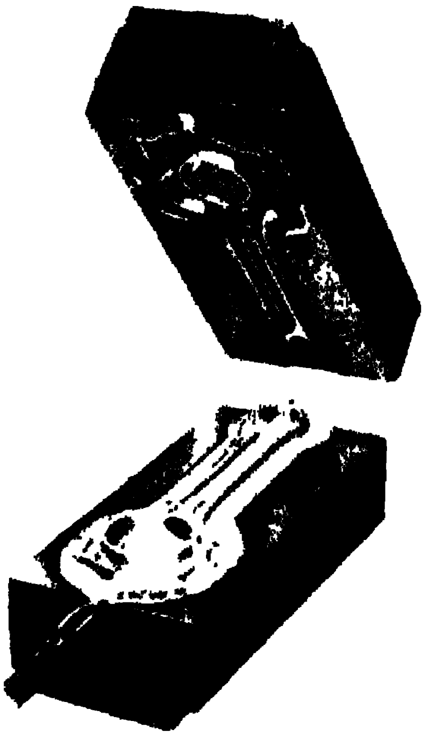

Fig. 7. Finishing Impression
Courtesy of Drop Forging Association, Cleveland, Ohio

After the finishing operation shown in Fig. 7, the forged connecting rod still has unformed metal or flash around the edge which must be trimmed. To accomplish this operation, a trimmer press is used to furnish the power, and a set of trimmer dies are employed to shear the excess metal correctly. The trimming operation is shown in Fig. 8. The dies shown are different in design from that of the ordinary set of trimmer dies. Punches are included for punching holes in both the crank end and piston end of the connecting rod. At the conclusion of the operation, the trimmed and punched product drops down inside the trimmer die. The trimmer punch used in this set of trimmer dies is machined so that it will force the forging through the trimmer blades. The trimming is done immediately after the finishing impression is completed and while the metal is still hot.

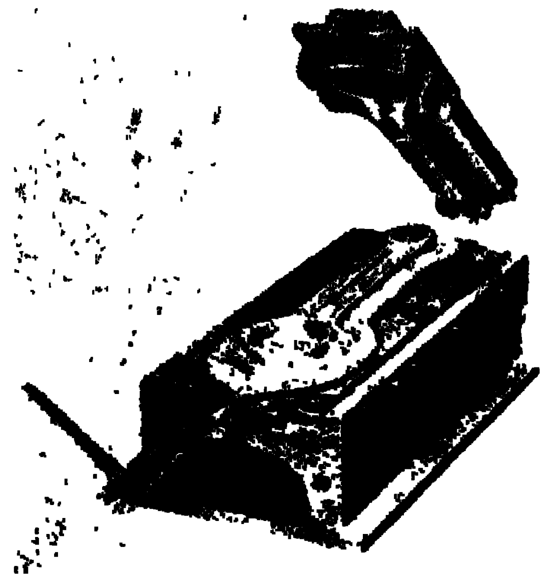

Fig. 8. Trimming Operation
Courtesy of Drop Forging Association, Cleveland, Ohio

Fig. 9 shows the trimmer dies after the trimming operation. The flash may be seen on the trimmer blades of the lower die, and the trimmed forging may be seen dropped down in the opening at the bottom of this die. The large punch in the front end of

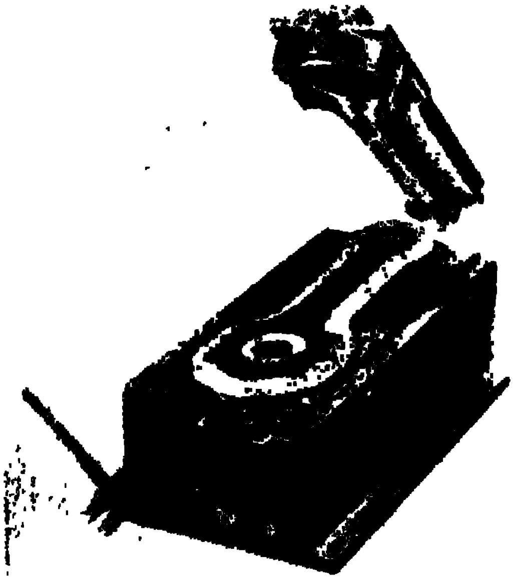

Fig. 9. Flash from Forging

Courtesy of Drop Forging Association, Cleveland, Ohio

the die has made a hole in the crank end of the rod, while the smaller punch has cut out a hole in the piston end of the rod. The finished forging is removed from the opening at the bottom of the trimmer die and is properly heat treated before final machining.

Fig. 10 shows the trimmed forging. The amount of machining and finishing necessary has been held to a minimum because of the precision work of skilled die sinkers who made the accurate closed-impression dies, and because of the experience of the forging craftsmen who carefully formed the required connecting rod to a close weight tolerance.

Forging of Parts with Holes, Pockets, and Recesses. Parts with holes, pockets, and recesses are rather difficult to forge. However, modern technical developments make it possible to forge such products with considerable success, if the necessary care of operation and precision in die design are adhered to. Notwithstanding the fact that there are physical and mechanical limitations on the extent to which metals can be deformed, many forgings with holes, deep depressions, and recesses are now being made by the drop-forging method. Of course, it must be borne in mind that no hole or depression in a drop forging may be larger at the bottom than at the top. In prac-

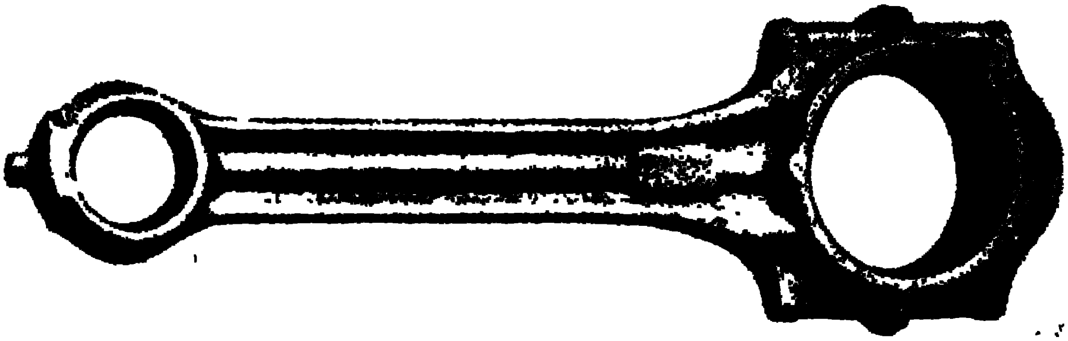

Fig. 10. Trimmed Forging

Courtesy of Drop Forging Association Cleveland, Ohio tice, it must be slightly smaller at the bottom than at the top by an amount equal to the draft or the angle on the side of the depression.

Forging parts with stems as projections from the main body of the forging demands special die design and forging techniques in order to produce parts without rupturing the fiber structures at any point. Proper matching of forging equipment and experience of the operator are necessary to insure sufficient impact pressure of the drop-forging hammer. This pressure must be enough to penetrate and thoroughly work the entire mass of the plastic metal. Such action is necessary for the full development of the physical properties inherent in metal, particularly steel.

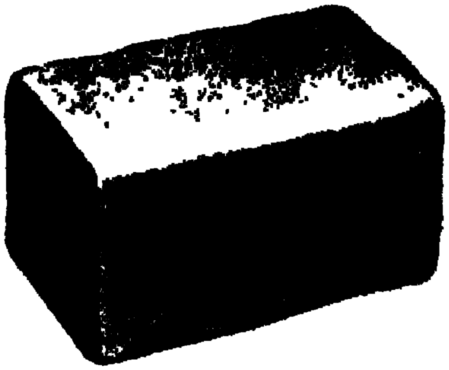

Fig. 11. Metal Stock
Courtesy of Drop Forging Association, Cleveland, Ohio

Fig. 11 shows a 6-inch square section of steel 10 inches long, which is used to forge a typical part with holes, pockets, and recesses. The stock is heated to the proper forging temperature before the forging operations are carried out.

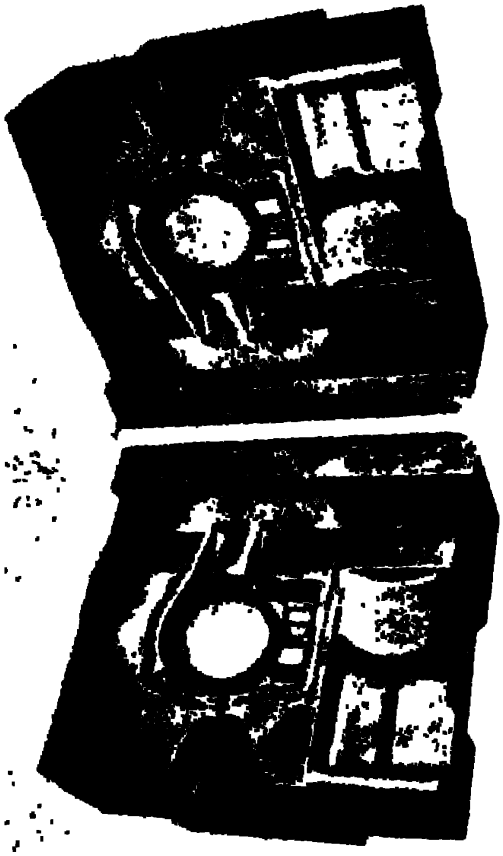

Fig. 12. Closed-Impression Dies
Courtesy of Drop Forging Association, Cleveland, Ohio

The blocking set of closed-impression dies for forming the required forging is shown in Fig. 12. The forging operations consist of fullering, rolling, blocking, and finishing. The fullering operation reduces the cross-section area of the stock that forms the largest projections. The remainder of the stock forms the circular and short projecting section of the product.

The fullering operation is followed by rolling and blocking operations. Rolling further reduces the cross-section area of the stock and proportions it to comply with the impressions in the blocking station of the dies. The proper distribution of metal accomplished by the rolling operation makes it possible for the metal formed in the blocking impressions to fill every cavity completely. The forging assumes its first definite shape after the blocking operation. Several successive blows of the hammer may be necessary to force the hot metal to flow into the die impression and completely fill it. The blocking operation is followed by punching through the center and then by finishing.

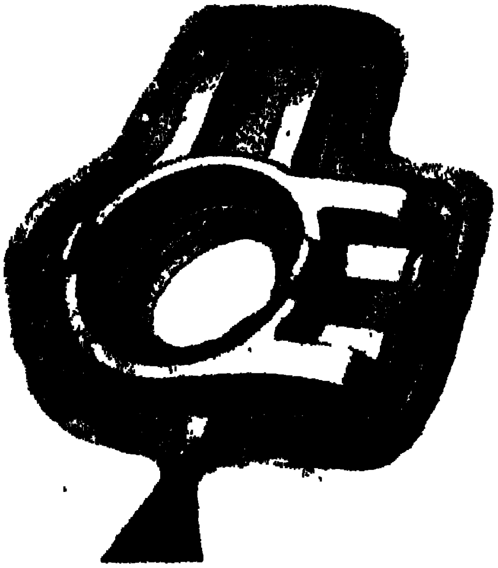

Fig. 13. Finished Forging with Flash

Courtesy of Drop Forging Association, Cleveland, Ohio

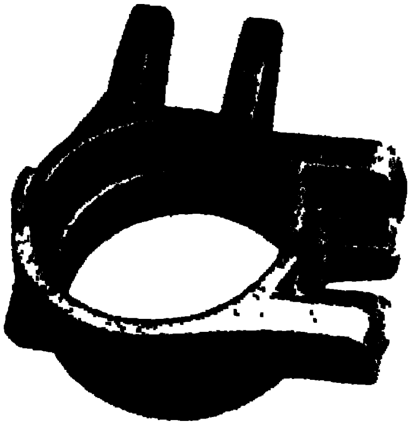

Fig. 14. Finished Forging After Trimming

Courtesy of Drop Forging Association, Cleveland, Ohio

Fig. 13 shows the finished forging with flash. A set of finishing dies is used to form the forging to its exact dimensions and close tolerances.

The unformed metal around the edge of the forging still has to be trimmed off, and the inside of the forging has to be punched. The trimmer dies are now employed for this purpose. Fig. 14 shows the finished forging, after trimming and punching, ready for heat treating and machining. The part shown in this figure furnishes an excellent example of a difficult forging. The thin walls of the circular section and the depth of this section and that of the projections pose a serious problem in designing die impressions and planning distribution of operations so that the metal will be forced to flow in the impressions and completely fill them. However, when an effective die design is attained and careful finishing operations are performed, the finished shape is held to close dimensional tolerances. In this manner the amount of machining and required finishing is kept to a minimum and labor costs are held down. A balanced combination of strength and toughness is also achieved throughout the entire part by the concentration of grain density and flow lines at points of greatest stress. A carefully planned sequence of forming operations insures achievement of these desirable characteristics in the finished products.

Forging of Parts with Thin Sections. Many parts having thin sections must possess a high strength-to-weight ratio By skillful forging, these parts are formed to close tolerances, thus avoiding excessive machining or finishing. Light sectional thicknesses and substantial reductions in weight are obtained without sacrifice of strength, because forging actually kneads the hot metal into a dense mass of flawless strength and makes it more resilient and wear resistant. Close temperature control and rapid blows of the forging hammer are necessary to assure uniformity of mass and dimension in the thin sections of the product if cold working of the metal is to be avoided. Cooling of thin sections of the metal in the dies is very rapid Forgings of this type are frequently subjected to impact stresses and severe vibration. To make forgings that can withstand these effects, a careful distribution of forging operations and properly designed dies are necessary. When these requirements are met, the maximum improvement of the physical properties inherent in the metal will be obtained.

Fig. 15 shows the metal stock for a typical forging. It is 2¼ inches in diameter and 14 inches long. Fig. 16 shows die blocks containing the proper impressions for finishing the forging of a riveter frame. When this forging is completed and the flash trimmed off, no further machining or finishing is necessary, except for drilling holes in the end bosses.

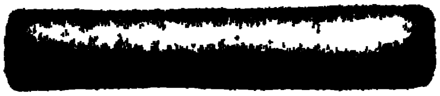

Fig. 15. Metal Stock

Courtesy of Drop Forging Association, Cleveland, Ohio

Fig. 17 shows the first forging operation, which is fullering. This operation reduces the cross-sectional area of the metal stock and elongates it to the required length, while gathering the necessary metal at either end to form the bosses. The fiber structure of the metal is elongated in this operation.

Fig. 18 shows the metal stock after it has been formed by bending to agree with the impressions sunk in the finishing dies. The purpose of the bending is to avoid a rupturing of the elongated fiber structure at any point throughout the length of the piece.

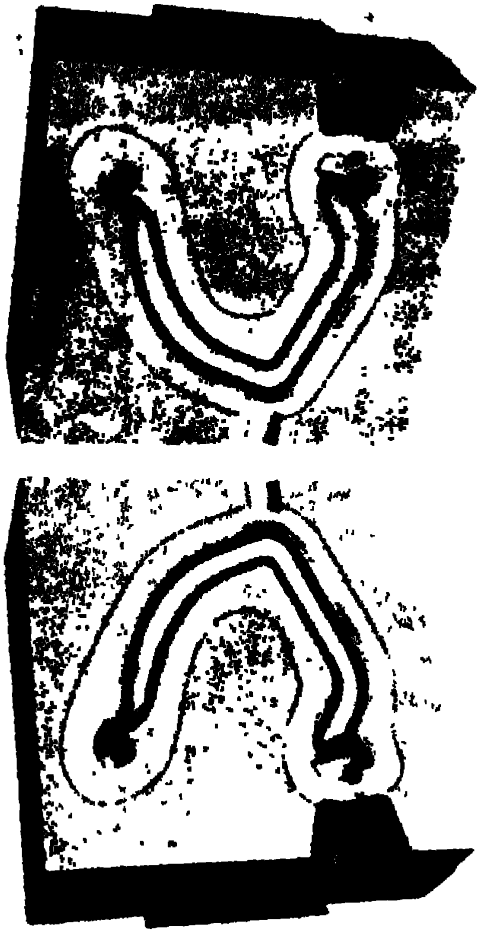

Fig. 16. Die Blocks Containing Finishing Impression
Courtesy of Drop Forging Association, Cleveland, Ohio

The last forging operation is the finishing of the bent stock in the proper die impressions. The flash around the edge of the forging is to be trimmed off in trimmer dies, after which only the drilling of holes in the end of the bosses is necessary to complete the part before actual service. Proper distribution of forging operations and carefully designed closed-impression dies result, in this instance, in a product well suited for hard usage in actual service. A compacting or concentrating of the fiber structure of the metal into a dense mass of strength and toughness has been accomplished under the rapid blows of the hammer. The product thus obtained provides generously for resistance to the vibration impact and torsional stresses to which the part will be subjected in actual service. The described forging procedure affords savings in material by virtue of the high strength-to-weight ratio of the part fabricated, and by the

Fig. 17. First Fullering Operation
Courtesy of Drop Forging Association, Cleveland, Ohio

elimination of machining and other finishing operations. Fig. 19 shows the finished forging after the flash has been trimmed off.

Forging of Parts Subject to Impact or Fatigue Loads. Parts which must stand up under the highly complex stresses of impact, fatigue, fluctuating loads, and reversing loads, must be made from metals of greatly improved quality. The design and manufacture of such forgings are greatly influenced by the working rule which directs: *achieve maximum strength for a given amount of weight.* When the safety of human lives is dependent upon the nonfailing performance of heavily stressed parts in an operating mechanism, it is recommended that these parts be forgings. This recommendation springs from the fact that the mechanical characteristics of forgings which depend upon the ductility of the metal (ability of forgings to elongate, to contract in area, to resist impact loading, etc.) increase in the longitudinal direction with continued hot working, yet remain about the same in the transverse direction. The ultimate strength and yield strength of the metal remain practically the same in the longitudinal and transverse directions.

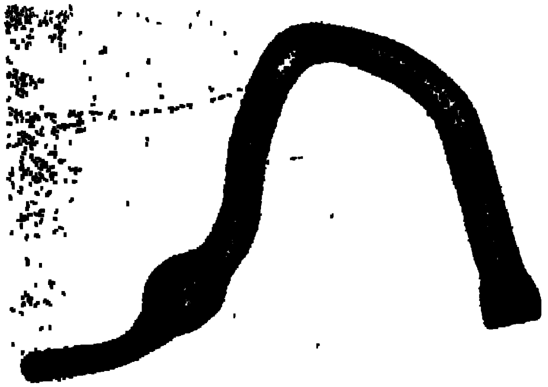

Fig. 18. Metal Stock After Bending

Courtesy of Drop Forging Association
Cleveland, Ohio

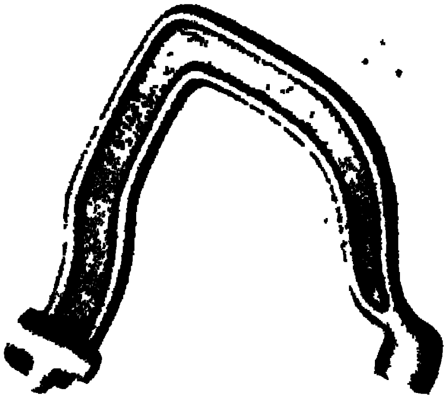

Fig. 19. Forging After Trimming

Courtesy of Drop Forging Association,
Cleveland, Ohio

Repeated reversal of stresses will ultimately cause fatigue in the metal unless it is properly worked and heat treated. When a part is subjected to such stresses, the specific portion of it carrying the fluctuating or reversing loads will alternately be in tension and in compression. If the part is properly forged, i.e., if proper forging technique and correctly designed dies are used, the required part will have a flawless fiber structure throughout. If these conditions are not met, the slightest concealed defect might eventually result in a fracture under severe service. It is recommended that sharp corners be avoided in the design of such forgings whenever possible, since acute corners are regarded as the most frequent cause of fatigue failures.

Fig. 20 shows stock prepared for a typical forging of a truck shackle. In its preliminary state, the stock is a cylindrical bar. After the metal is heated to a plastic state, a tonghold is drawn for convenience of handling the heated stock in the subsequent forging operations. The metal is then ready for forming in the dies.

Fig. 20. Metal Stock

Courtesy of Drop Forging As
Cleveland, Ohio

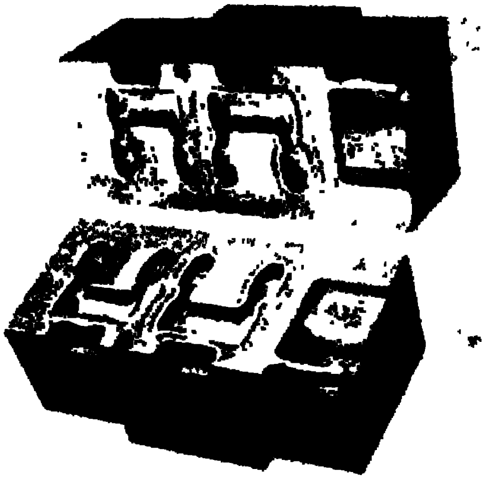

Fig. 21. Closed-Impression Dies

Courtesy of Drop Forging Association,
Cleveland, Ohio

One set of closed-impression dies are designed to perform all the necessary forging operations of shaping the required part and distributing the metal in such manner that the strength-giving flow-line structure inherent in the steel is not interrupted. When the die-forging procedure is followed to best accomplish these objectives, the part produced will have a maximum resistance to stresses, when it is applied in actual service. Fig. 21 shows the set of dies used to forge the truck shackle.

After the tonghold is drawn on the stock, the first operation is carried out in the edging impression of the dies. There the stock is broken at one end to provide enough metal to fill the die cavity where the bracket portions of the shackle are formed. Then follows the blocking operation in the blocking impression of the dies, where the side brackets and rough contour of the shackle body are formed. The proper metal distribution and positioning of the fiber structure are completed at this stage. The finishing impression of the dies is now employed, where the correct shape of the part is obtained and the required surface finish is imparted to it in order to eliminate costly machining or finishing as much as possible. The development of the metal quality required for maximum strength and resistance to service stresses is also completed in the finishing impression of the dies. A final hot-trimming operation removes the flash metal forced away from the die impressions at the time the part was forged. Fig. 22 shows the 14-pound trimmed forging.

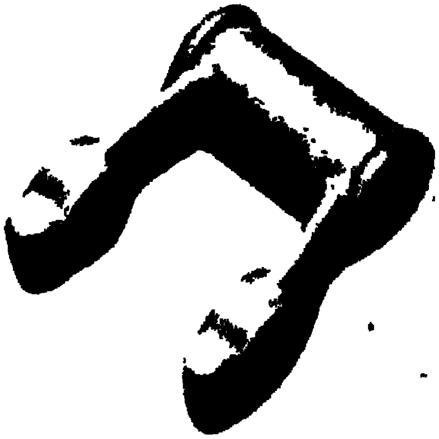

Fig 22. Completed Forging

Courtesy of Drop Forging Association, Cleveland, Ohio

Forging of Steel Balls for Ball Bearings. The first operation in which steel emerges in the shape of a ball is either a cold or hot forging, the latter being employed for the larger sizes. In forging steel balls, wire is fed through a cut-off die where a slug, shown in Fig. 23, is sheared off and formed roughly round between hemispherical dies. By careful control of the diameter and length of slug, balls are forged with the least amount of flash. Fig. 24 shows the forged ball, and Fig. 25 shows the dies.

Fig. 23 Metal Stock

Courtesy of New Departure, Bristol, Conn

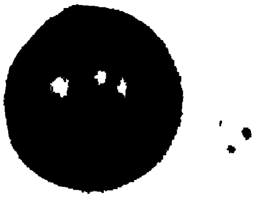

Fig 24 Forged Ball

Courtesy of New Departure, Bristol, Conn

The making of a tough, spherical, rolling member is well under way upon completion of the die work. However, the forging process sets up certain internal stresses which must be relieved. Proper heat treating or normalizing of the forged balls in special furnaces, and subsequent slow cooling to room temperature relieve the objectionable stresses set up in the forgings.

After heat treating and cooling, the steel balls are ready for rough grinding in centerless grinding machines, where they are fed into and held against the side of a grinding wheel by a specially designed pressure plate. Direction of ball rotation is opposite to that of the grinding wheel, and the ball path is such as to continually dress the wheel. The balls emerge from this operation a few thousandths of an inch out of round and considerably oversized.

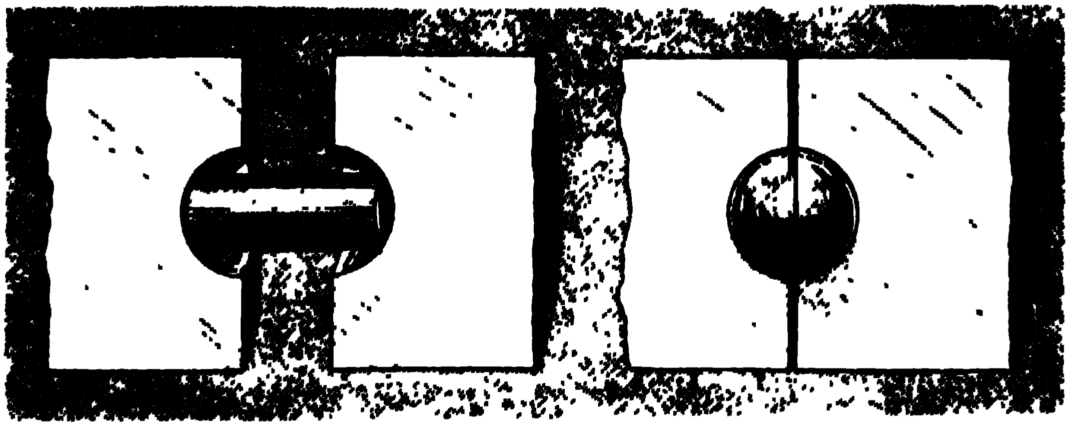

Fig. 25. Forging Dies

Courtesy of New Departure, Bristol, Conn

The next operation is a careful heat treating of the roughly ground balls, which is given to make them extremely hard, yet tough. The operation consists of uniformly heating them to the correct temperature, and then quenching them in oil or water depending upon the size of the balls. Tempering in electric furnaces follows.

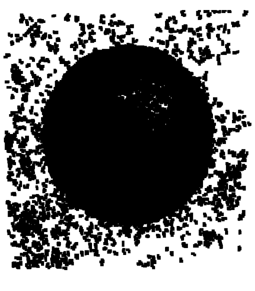

Fig. 26. Finished Ball

Courtesy of New Departure, Bristol, Conn

Finish grinding, lapping, and polishing complete the processing of the balls and make them suitable for actual service after final, precision inspection. Fig. 26 shows the finished ball.

Forging of Irregular Shapes, Several at One Time. The method of forging several parts at one time may effect economies and result in a more efficient hot working of the metal, especially if the shape of the part indicates the advisability of producing two or more pieces as a single forging and separating the parts at the time the flash is trimmed. Forging several pieces at one time may accomplish a double purpose: economy of faster production and use of simpler forging operations. Irregular shapes are often grouped to develop a more suitable symmetry in the forging, which allows the die to be of simpler design. In many instances, this method of forging can save metal and reduce wear on the dies, thus increasing die life. Grouping of parts may often be planned not only for irregular shapes but also for parts that have sufficient symmetry for economical forging as a single part. The grouping of such parts will definitely result in faster production without loss of quality.

Fig. 27. Metal Stock

Courtesy of Drop Forging Association, Cleveland, Ohio

This method of multiple forging is used to advantage in the production of such an item as a carbon-steel guide bracket. This part is made two at a time from a cylindrical bar cut to required length, as shown in Fig. 27.

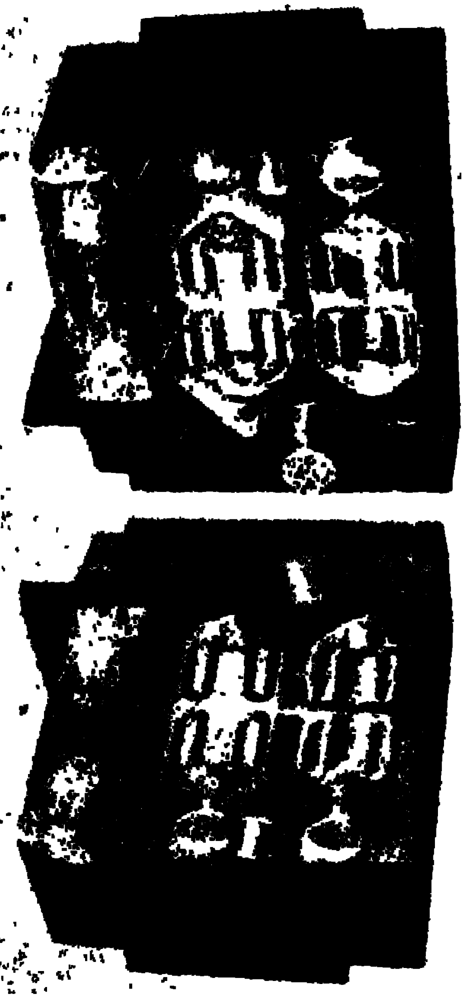

Fig. 28. Closed-Impression Dies

Courtesy of Drop Forging Association, Cleveland, Ohio

One set of dies, shown in Fig. 28, carries all the necessary impressions for forging two guide brackets at the same time.

The necessary forging operations are carried out after heating the bar to the correct forging temperature. The first operation is edging or breaking the heated bar, which prepares the ends of the bar for subsequent forming of the bosses and distributes sufficient metal in the center of the bar for shaping the slotted projections.

The next operation is carried out in the blocking impression of the dies. The metal is properly distributed to fill the die cavities without interrupting the continuity of the inherent flowline structure of the forged metal. This operation forms the rough shape of the part.

The final shape is forged to close-dimensional tolerances in the finishing impression of the dies. The required surface finish is also imparted to the work in this operation, thus reducing to a minimum the amount of finish machining required. The forged parts with the thin flash metal around them are shown in Fig. 29.

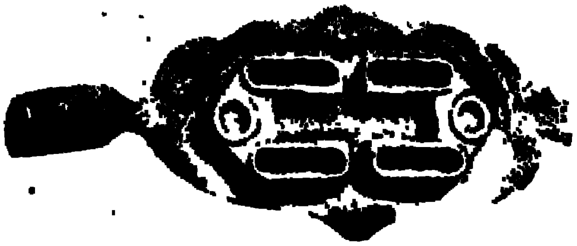

Fig. 29. Forgings in Finishing Impression of Dies

Courtesy of Drop Forging Association, Cleveland, Ohio

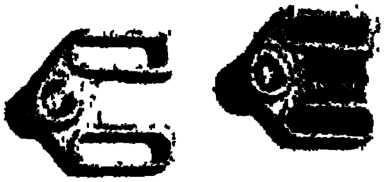

Fig. 30. Completed Forgings

Courtesy of Drop Forging Association, Cleveland, Ohio

The flash is removed in a cold trimming operation in the trimmer press. The completed forging, after the flash has been trimmed away, requires only cold punching of the bracket projections, and drilling and broaching of the center hole. Positioning of the metal in the preliminary forging operations has provided proper distribution to insure maximum strength and toughness throughout the part to resist severe stresses in actual service. The upper half of Fig. 30 shows one forging after the flash around it has been trimmed away. The lower portion of the illustration shows a forging that is more completely finished; the bracket projections have been cold punched through.

Fig. 31. Metal Stock

Courtesy of Drop Forging Association, Cleveland, Ohio

Forging of Parts with Projections and Bent Sections. Careful design and skilled forging technique are required for producing parts with unusual projections or bent sections. A forging of a starter pedal furnishes an excellent example of a part that is difficult to produce. The operations necessary for forging this part are shown in the accompanying illustrations. The operations must be carefully planned so that the die cavity will be properly filled with heated metal, and so that the hammering results in a fiber structure of the metal which is unbroken at points of greatest service stress. One such point of stress is at the right-angle section of the starter pedal.

Fig. 31 shows the 1¼-inch diameter, cylindrical stock that is cut in a length sufficient to make three forgings. Fig. 32 shows the single set of closed-impression dies which is required for the drop forging of the starter pedal.

The forging operations for producing this part correspond to the four stations or cavities in the closed-impression dies. The operations are arranged in the following order. In the first operation, one end of the heated bar is flattened to provide metal for the thin section of the part, while additional stock is concentrated for later forming of the high boss. Fullering, the second operation, follows. It elongates the bar beyond the boss section to form the shank and pedal end of the part. Blocking, the third operation, next shapes the forging and forms the right-angle bend for the pedal section, without interrupting the continuity of the fiber structure in the metal.

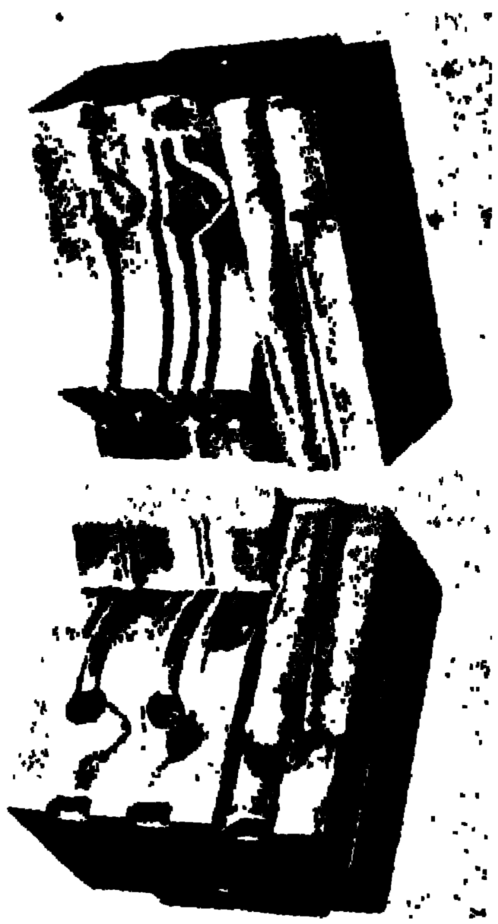

Fig 32. Closed-Impression Dies

Courtesy of Drop Forging Association, Cleveland, Ohio

Fig. 33 shows the part after the fourth operation, which consists of final shaping to the size and surface finish required in the finishing impression of the dies. The flash metal squeezed out between the die faces when the cavities are filled in forging is then trimmed off with neat precision in a trimmer press with a set of trimmer dies.

After the flash metal has been trimmed away, the shank of the starter pedal is straightened to complete the forging operations. The forged part requires no excess machining or finishing, except for the drilling of holes. The uninterrupted flow lines are maintained throughout by the design of the closed-impression dies. This enables the metal, improved in all direction by the forging operations, to preserve its maximum strength and toughness for resistance at those points where service stresses are calculated to be most severe. Fig. 34 shows the completed forging after trimming and straightening.[1]

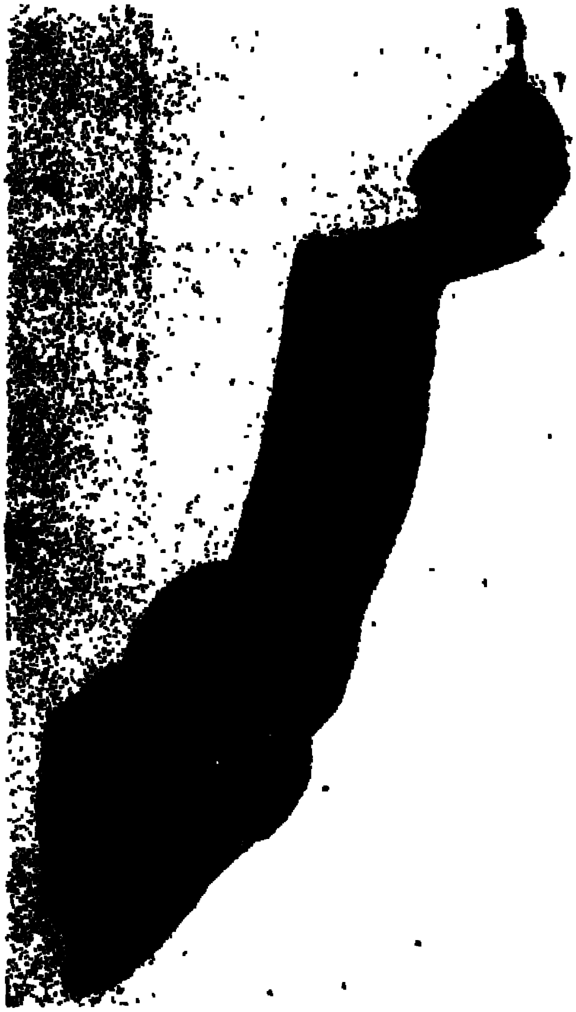

Fig. 33. Final Shaping in Finishing Impression

Courtesy of Drop Forging Association, Cleveland, Ohio

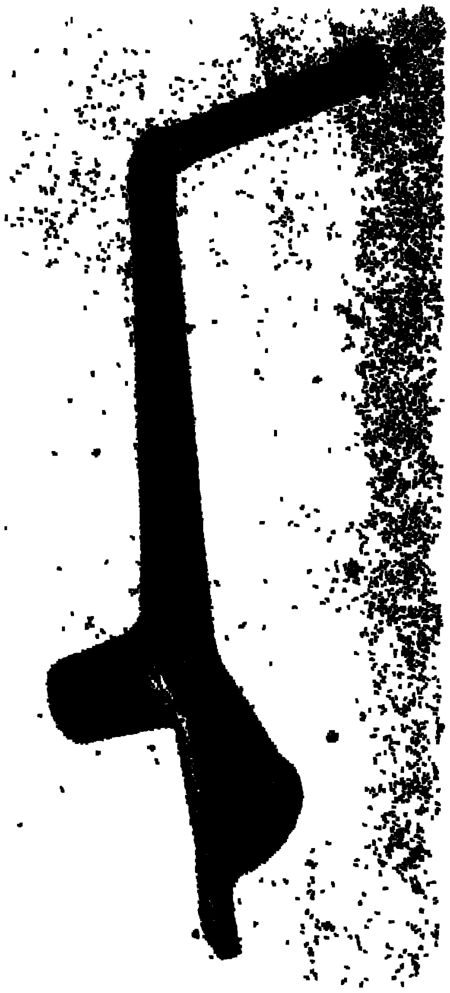

Fig. 34. The Same Forging after Trimming

Courtesy of Drop Forging Association, Cleveland, Ohio

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[1] Discussion in this chapter is based upon information contained in *Metal Quality*, published by the Drop Forging Association, Cleveland, Ohio, 1949. Adapted with permission.

REVIEW QUESTIONS

1. Describe briefly the sequence of mechanical operations carried out in forging a diesel-engine connecting rod, as shown in Figs. 1, 2, 3, 4, and 5 of this chapter.

2. Describe briefly the sequence of remaining operations carried out in forging the connecting rod, as shown in Figs. 6, 7, 8, 9, and 10 of this chapter.

3. What is the practice followed when forging parts with holes, deep depressions, and recesses?

4. Describe briefly the sequence of operations carried out in forging a part with holes, pockets, and recesses, as shown in Figs. 11, 12, 13, and 14 of this chapter.

5. Describe briefly the sequence of operations carried out in forging a part with thin sections, as shown in Figs. 15, 16, 17, 18, and 19 of this chapter.

6. Name some of the recommendations for successful forging of parts which are to be subjected to repeated reversals of stress.

7. Describe briefly the sequence of operations carried out in forging a truck shackle, as shown in Figs. 20, 21, and 22 of this chapter.

8. Describe briefly the sequence of operations carried out in forging a steel ball bearing, as shown in Figs. 23, 24, and 25 of this chapter.

9. Describe the heat-treating and other finishing operations performed in the making of ball bearings.

10. Discuss the possibility of forging irregular shapes, several at one time.

11. When may a grouping of parts for forging be successfully planned?

12. Describe briefly the sequence of operations carried out in the multiple forging of a part, as shown in Figs. 27, 28, 29, and 30 of this chapter.

13. Name some of the recommendations followed in forging parts with projections and bent sections.

14. Describe briefly the sequence of operations carried out in forging the starter pedal, as shown in Figs. 31, 32, 33, and 34 of this chapter.

CHAPTER VII

Press Forging

Press Forging Operations with Flat and Closed-Impression Dies. These forging operations employ a slow squeezing action in order to deform the plastic metal to the desired shape. The pressure, being slowly applied, allows time for flow of the metal, and the effect penetrates deeply into the metal. The pressures exerted on the heated metal range from 1 ton to over 25 tons per square inch. Most of the presses employed in this method of forging are of the hydraulic type. Comparatively large forgings that would require heavy hammers to shape them may be formed by hydraulic presses which are much smaller. Press action results in deeper penetration of the beneficial effects obtained by forging; thus, the center portion of a large forging is worked to a more satisfactory degree than would be possible by action of a hammer.

Large ingots of hexagonal and octagonal shapes weighing up to 250 tons are forged on hydraulic presses. These presses are also used for upsetting and punching, for trepanning large parts, and for hot drawing long drums. Trepanning consists of piercing a hot ingot and working it over a mandrel to produce a hollow cylinder such as a gun barrel or other tubular-shaped piece. Large crankshafts weighing up to 50 tons, shafts of large diameter, boiler drums, and 16-inch naval guns are among the large forgings produced on hydraulic forging presses. Fig. 1 shows a massive hexagonal steel ingot pressed to the shape desired in a hydraulic forging press. Some of the presses built for extremely heavy work are capable of exerting pressures exceeding 15,000 tons.

Open-die forgings are mostly produced by press forging. Open-die forgings are made between flat dies or dies with a groove of

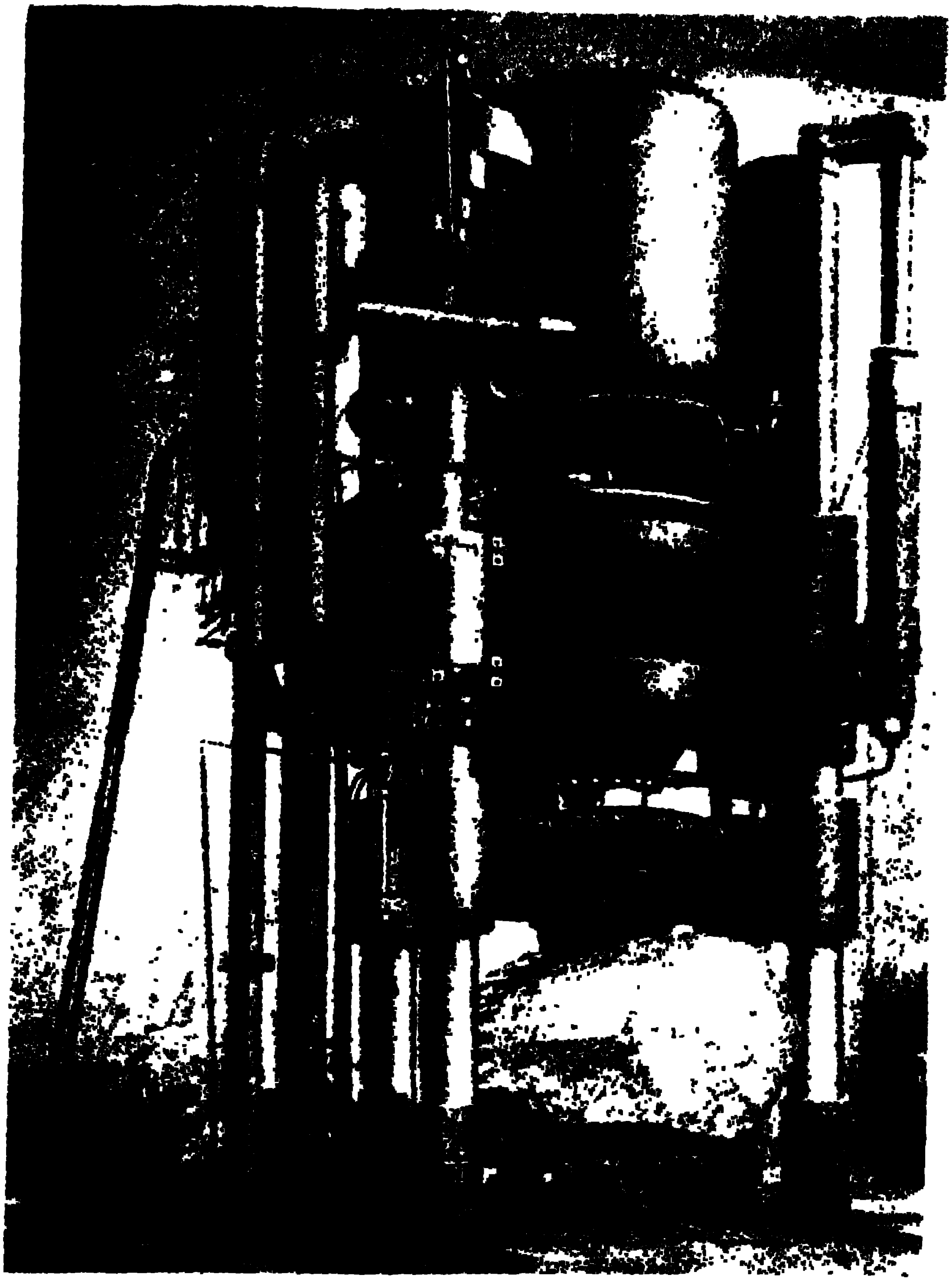

Fig. 1. Hydraulic Press Forging a 200,000-Pound Ingot

Courtesy of Mesta Machine Company, Pittsburgh Pa.

simple shape. Properly speaking, there are no impressions sunk in the face of these dies.

However, press forging operations also can be applied in the production of small and medium-size parts of simple design by using closed-impression dies. Only a single stroke of the ram is required for a particular impression in the die. The impressions or cavities are sunk or machined in the face of these dies. Most of the total energy that is available in the forging press is transmitted to the metal, whereas in the case of drop-forging hammers, the impact is absorbed to a large extent by the machine and its foundation. A distinct advantage of press forging lies in the fact that press reduction of the forged metal is more rapid than it is in drop-forging operations. Hence, a saving in labor cost is effected, and the products are found to offer greater accuracy than do those produced by drop-forging methods. On the other hand, parts of irregular or complicated shape are more economically produced by drop forging. The presses proper may be of the mechanical or hydraulic type, and the products may be made from ferrous or nonferrous metals.

Open-Die Forgings. These are forgings that are made with open dies. The heated metal is forged between two flat dies, or dies that have a groove of simple shape, such as V-shape, half-round, or half-oval. This type of work may also be finished or sized between swages or similar tools which are struck by the dies. The foremost advantage of this process is its flexibility. Refinement and directional characteristics of the metal are developed by planning the forging operations that will give optimum combination of properties where they are most needed. The amount and direction of hot mechanical working serve to establish the characteristics of the metal to give maximum serviceability. The mechanical properties of these forgings are normally determined from test pieces taken from the forgings themselves, either from locations in the body of the forging or from full-size prolongations provided for this purpose.[1]

Forgings of numerous types and sizes are produced with open dies as previously described. These forgings may be used in various industries, where they are more adaptable than forgings produced by means of closed-impression dies. Certain commodity forgings, such as die blocks, are produced for special purposes. In making these products, the manufacturer chooses such a process and practice which he, through experience, knows will produce parts satisfactory for their particular service. Fig. 2 shows one step in the forging of Mo-Lyb-Die processed die blocks as followed by A. Finkl and Sons Company of Chicago. Only highest quality steel is used in these die blocks.

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[1] Discussion of open-die forgings in this paragraph is adapted from *Manual of Open Die Forging*, published by the Open-Die Forging Industry, New York, 1949.

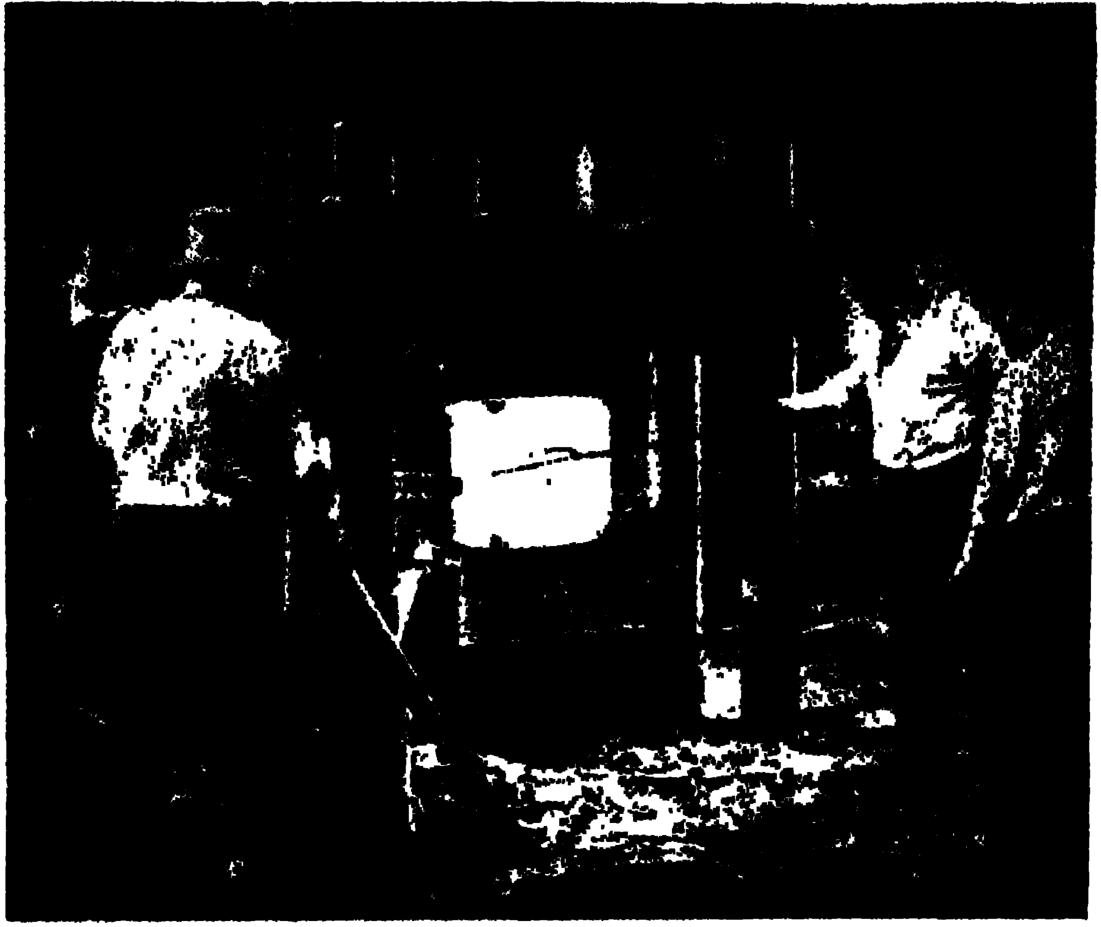

Fig. 2. Forging a Die Block

Courtesy of A. Finkl & Sons Company, Chicago, Ill.

Steel ingots, blooms, and billets used for these die blocks are almost entirely of electric-furnace quality. The steel ingots usually weigh from 3 to 20 tons, and are of square cross section with rounded corners. These are converted into blooms, billets, and slabs which are reheated and rolled into their final shape. Each heat is chemically analyzed and physically tested before being processed into a die block. The initial processing consists of press forging and upsetting the die block in order to obtain the continuous fiber flow in the block, which improves its physical properties. After the forging operations, the cooling of the die block is scientifically controlled to reduce the possibility of thermal rupture, and to prepare it structurally for subsequent heat treating operations. Carefully controlled heat treatment assures maximum penetration and uniformity of hardness. Fig. 3 shows a pair of finished, quenched, and tempered, closed-impression dies—dies made from the steel blocks which were forged by the open-die process from alloy steel billets.

High-quality, dependable, heavy-duty, custom forgings must be processed from special alloy steel. Skill, experience, and modern facilities are necessary for accomplishing the above requirements. Chromium-nickel-molybdenum forgings, or the equivalent, are selected for strength, stamina, and fatigue resistance in order to withstand the severe stresses imposed by heavy-duty operation of modern-day machinery. These forgings are made on hydraulic presses having squeeze pressures ranging from 300 to 2,000 or more tons, with open dies.

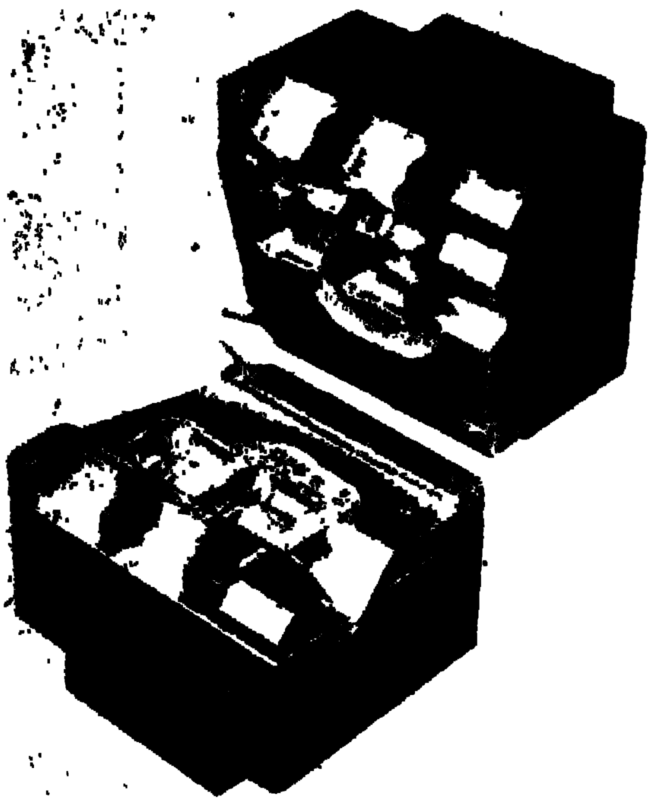

Fig. 3. Pair of Finished Closed-Impression Dies
Courtesy of A. Finkl & Sons Company, Chicago, Ill

Much consideration is given to the proper working of the center of the ingot, bloom, or billet. The forgings are properly heat treated after the hot-working operations. The heat treating consists of annealing before machining, followed by hardening after machining, either in oil or by normalizing in air, depending upon specifications. Fig. 4 shows a 2,000-ton forging press working a 54-inch ingot into a reduction gear shaft.

Other high-grade steel products forged with open dies include: containers, liners, and plungers for extrusion processes; crankshafts for trimming presses, punch presses, mechanical forming presses, nail machines, engines, and pumps; shafting for all types of heavy machinery; heavy armature shafts; large gear shafts; arbors for heavy rolls; plastic-mold die blocks; die-casting die blocks; locomotive axles, crank pins, and piston rods. These forgings may vary in weight from a few pounds to fifty tons.

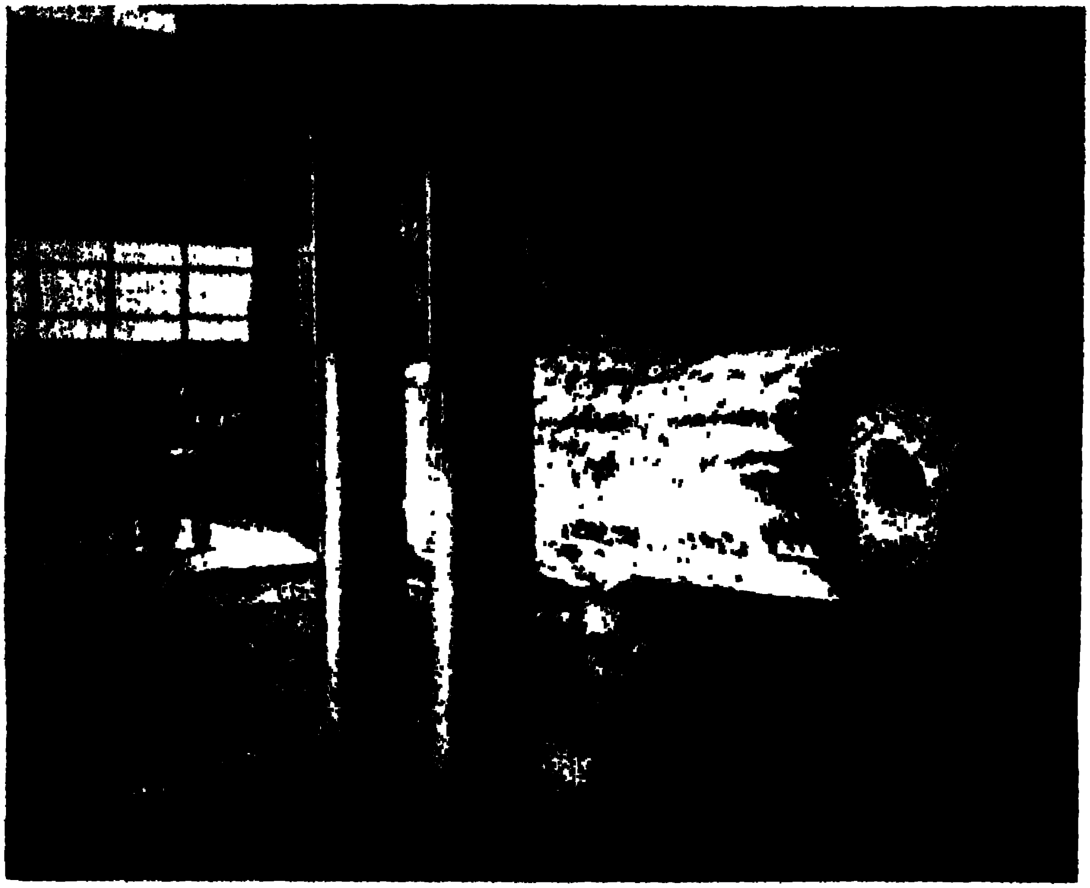

Fig. 4. A 2,000-Ton Forging Press in Operation

Courtesy of A Finkl & Sons Company, Chicago, Ill

Fig. 5 shows a typical array of heavy forgings ready to be finished in the machine shop. Included in the picture are a 48-foot walking shaft for an excavating machine; a rough turned and heat treated double-throw crankshaft for a heavy-duty forming press; a forged. 5-inch, forging machine crank; a group of forged laundry-wringer rolls; and a sleeve for a backing-up roll.

Mechanical and Hydraulic Forging Presses. These presses are used for a large variety of forged products, but are particularly suited to forging small symmetrical steel and nonferrous metal parts whose material offers relatively low resistance to deformation in the plastic state. Sizing operations on many types of steel forgings already formed in drop hammers and forging machines are also adaptable to the forging press, While drop-hammer forging accounts for the greatest percentage of forged parts, many products are adapted to production on the forging press and the forging machine or upsetter. The latter type of machine is treated in detail in the next chapter of this text. Forging presses and forging machines are used for work where, in the opinion of the forging engineers, the best and most economical product can be obtained on this type of equipment. The size and shape of the product, the number of operational steps, the cost of tooling the volume production, and other factors determine the manufacturing method for the particular product. The advantages of closed-impression die forging in improvement of metal are obtained, of course, and insure the same high-quality product as that produced by the more frequently used drop-hammer method.

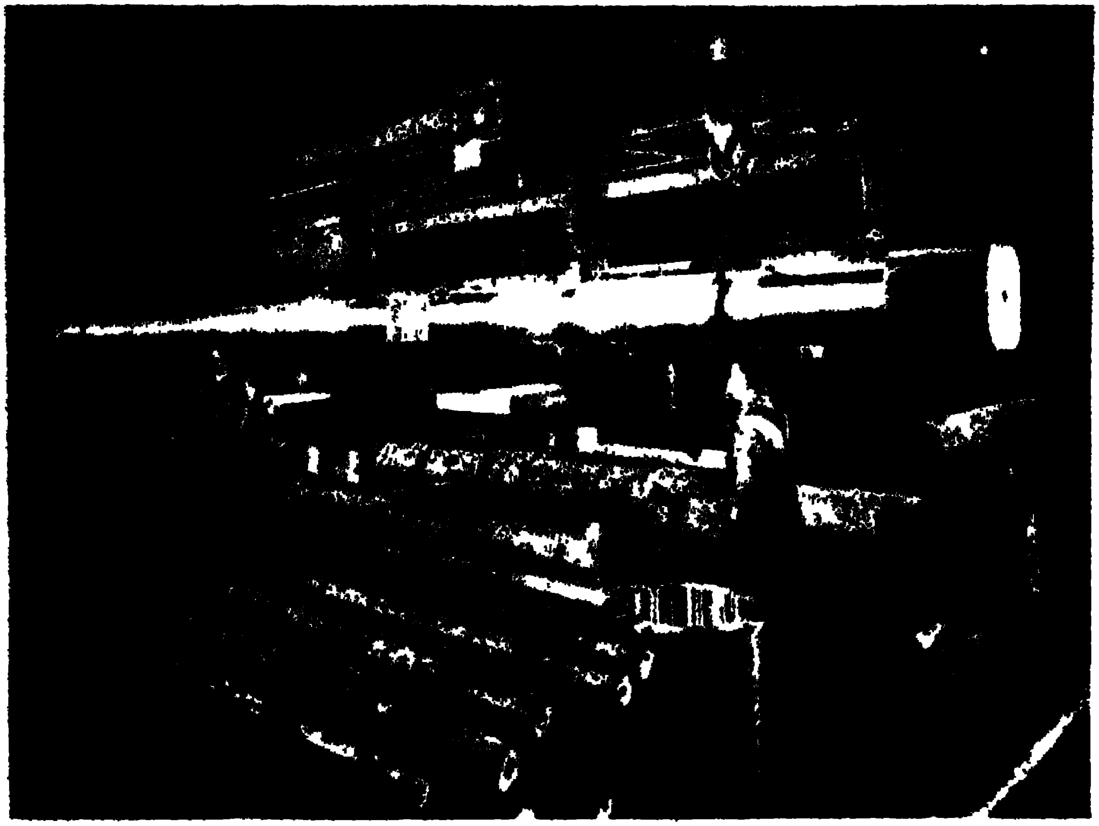

Fig. 5. Assorted Heavy Forgings

Courtesy of A. Finkl & Sons Company, Chicago, Ill.

The mechanical forging presses are designed rigid, well-aligned, and for high-speed operation. They vary in size from 500-ton models to 6,000-ton models. Fig. 6 shows an Ajax, 2,000-ton, high-speed, mechanical forging press in operation, one specially constructed for high production of impression-die forgings, from steel, aluminum, magnesium, copper, brass, and stainless alloys. It is equipped with a powerful air clutch, shown at the right, and mounted directly on the main eccentric shaft which permits higher operating speeds, quicker sequence of blows and, consequently, higher production.

The pneumatically operated clutch is of the multiple-disk friction type. It is direct, rapid, and smooth in operation and is controlled by a foot pedal. This design of instant response makes it possible to complete multi-operation forgings in one heat, thus yielding increased production. The driving power of the flywheel and the motor, shown at the left in Fig. 6, is transmitted to the back shaft of the press through a safety friction hub of the flywheel which slips, when its torque has been exceeded, before damage is done to the press through overload or accident.

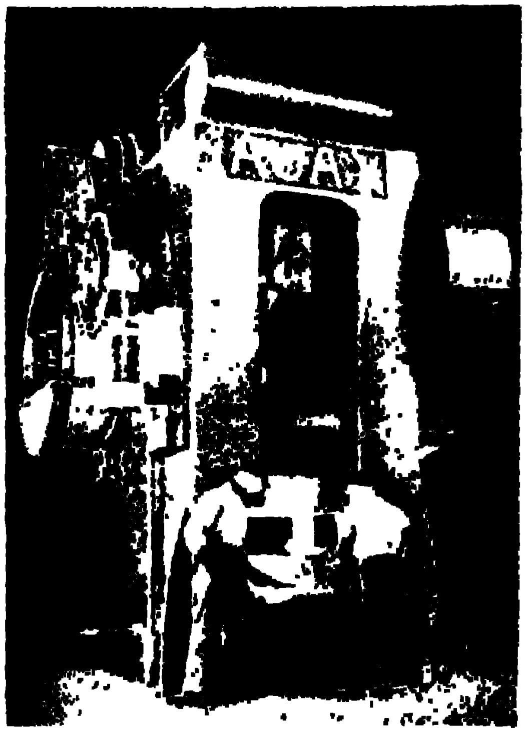

Fig. 6. Ajax 2,000-Ton High-Speed Forging Press

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

A reasonable comparison of forging presses with steam or board drop-hammer sizes is made by multiplying the ton rating of the forging press by 2 or 2½. Thus, the forging press shown in Fig. 6 has a forging capacity approximately that of a 4,000-pound steam or a 5,000-pound board drop hammer. The accuracy of the forgings produced and their quality make them compare well with the products of other forging methods.

(Additional benefits to the product, such as increased strength and toughness, may be obtained through use of improved heating methods, such as the electrical induction and controlled atmosphere heating methods. The electrical induction heating method consists of placing the metal in a furnace which is essentially an air transformer, and then passing a high-frequency current through a water-cooled copper tube constituting the primary coil of the transformer. A heavier secondary current is induced in the metal constituting the secondary coil. The resistance of the metal will cause it to heat up greatly. Accurate control of this heating to the desired temperature is accomplished by regulating the length of time that currents are induced in the metal. A controlled atmosphere in a furnace is obtained by designing the furnace so that the heated metal will be prevented from contacting oxygen of the surrounding air. In some of these furnaces, provision is made for reducing gases, such as carbon monoxide or hydrogen, to enter into the furnaces and surround the heated metal, thus creating a screen or shield around the metal and preventing it from oxidizing, i.e., coating with an iron oxide scale.

Hydraulic descaling (using hydraulic pressure to remove scale from the surface of the heated metal) and the use of harder die steels may contribute to additional improvement of the product. The harder die steels are suitable because of the absence of impact in the use of forging presses. Forging presses are employed also for hot and cold coining of stampings and forgings made by other high-production operations—an arrangement that results in cost savings.)

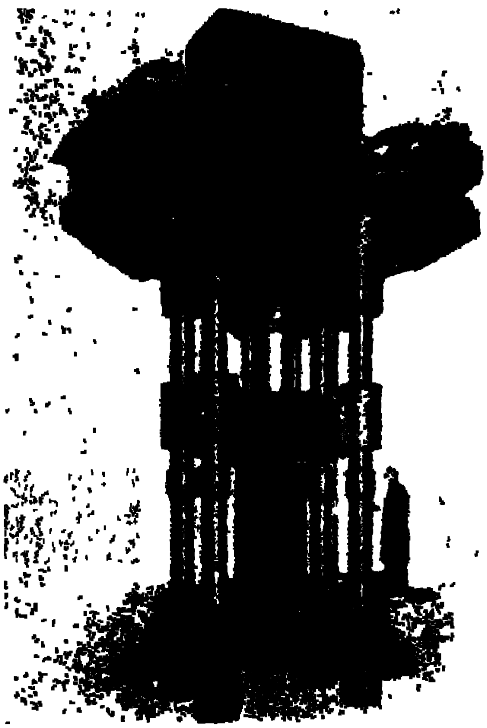

Fig. 7. A 1,000-Ton Hydraulic Press with 42-Inch Ram Travel

Courtesy of The Hydraulic Press Manufacturing Company, Mount Gilead, Ohio

In hydraulic forging presses, the ram is moved by the pressure of a fluid. Oil is mostly used in the modern presses, but other fluids such as water are also used. Steam may also be employed to furnish the pressure necessary for moving the ram of the press. In order to speed up the working cycle of hydraulic-press forging, the hydraulic circuit is designed to accomplish a rapid traversing speed of the ram, and a comparatively slower speed of the actual forging. Flexible control permits adjustment of the length of the stroke and pressure. In some presses, the system can be adjusted to reverse automatically when a preset pressure is reached. Fig. 7 shows a 1,000-ton hydraulic press with a 42-inch ram travel.

The press shown in Fig. 7 may be equipped for flat-die or closed-impression-die forging. Hydraulic pressure is provided by two piston-type generators, each driven by an electric motor. The hydraulic circuit in hydraulic presses is designed in various manners to give the most efficient working stroke. In many presses, a pump supplies oil under pressure to the main cylinder and to the rapid-advance ram. Oil escapes from return cylinders through a holding valve. A prefill valve is arranged to stay open while the ram advances and returns rapidly, thus permitting free flow between the main cylinder and reservoir. To hold the ram in an elevated position between strokes, the pump, being at rest, allows the oil to bypass through the pump valve to the reservoir. The oil is held in the return cylinders by the holding valve. Oil is used as a fluid in many modern hydraulic presses. Water, however, is the operating fluid used in large presses. Accumulator cylinders are arranged in these presses

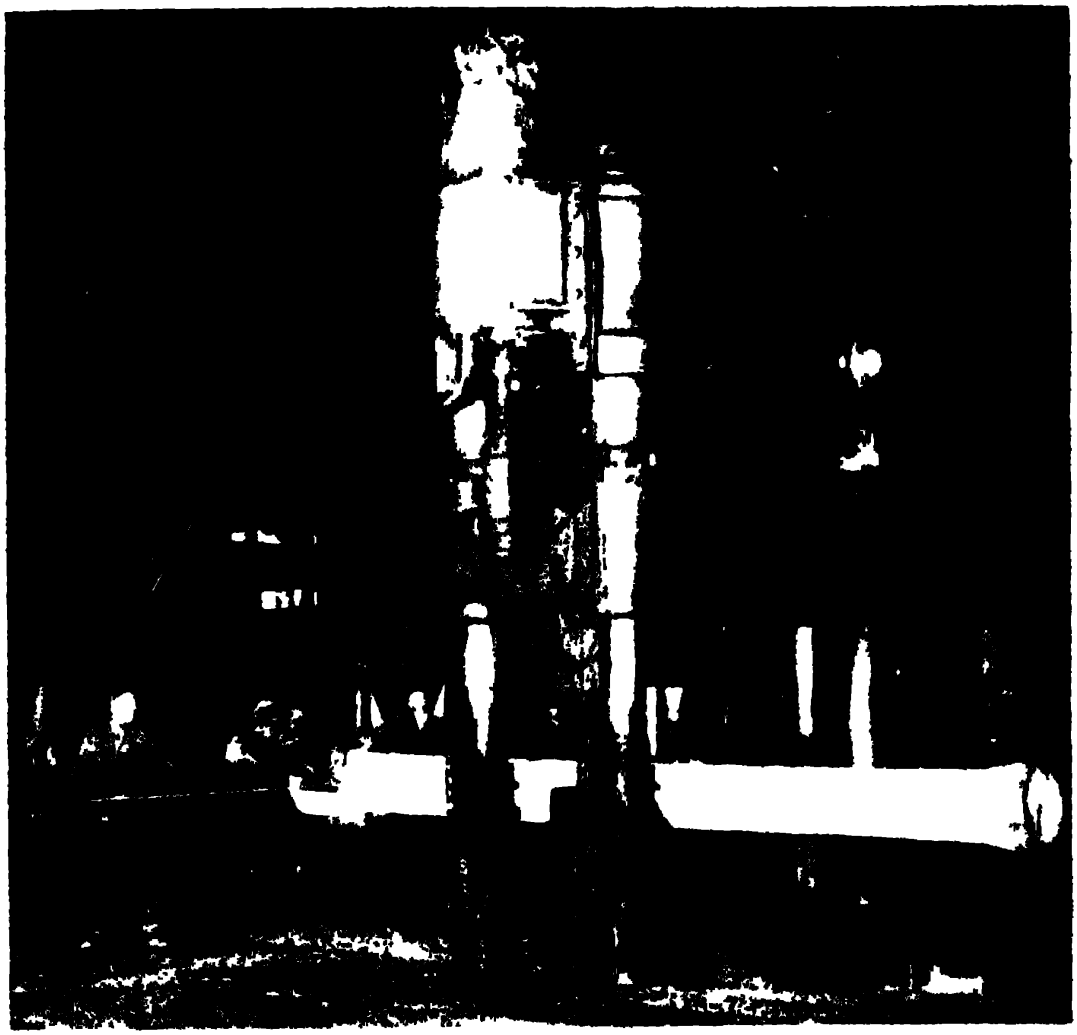

Fig 8 Drawing Out a Shaft under a 1,000-Ton Press

Courtesy of Bethlehem Steel Company, Bethlehem, Pa to build up pressure. The newest development is a combination of a mechanical press of the screw type with hydraulic pressure, which is employed to move the slide or ram with a flywheel. The energy stored up in the flywheel is utilized on the down stroke. This combination results in a rapid advance and return stroke, thus increasing the production of forgings considerably.

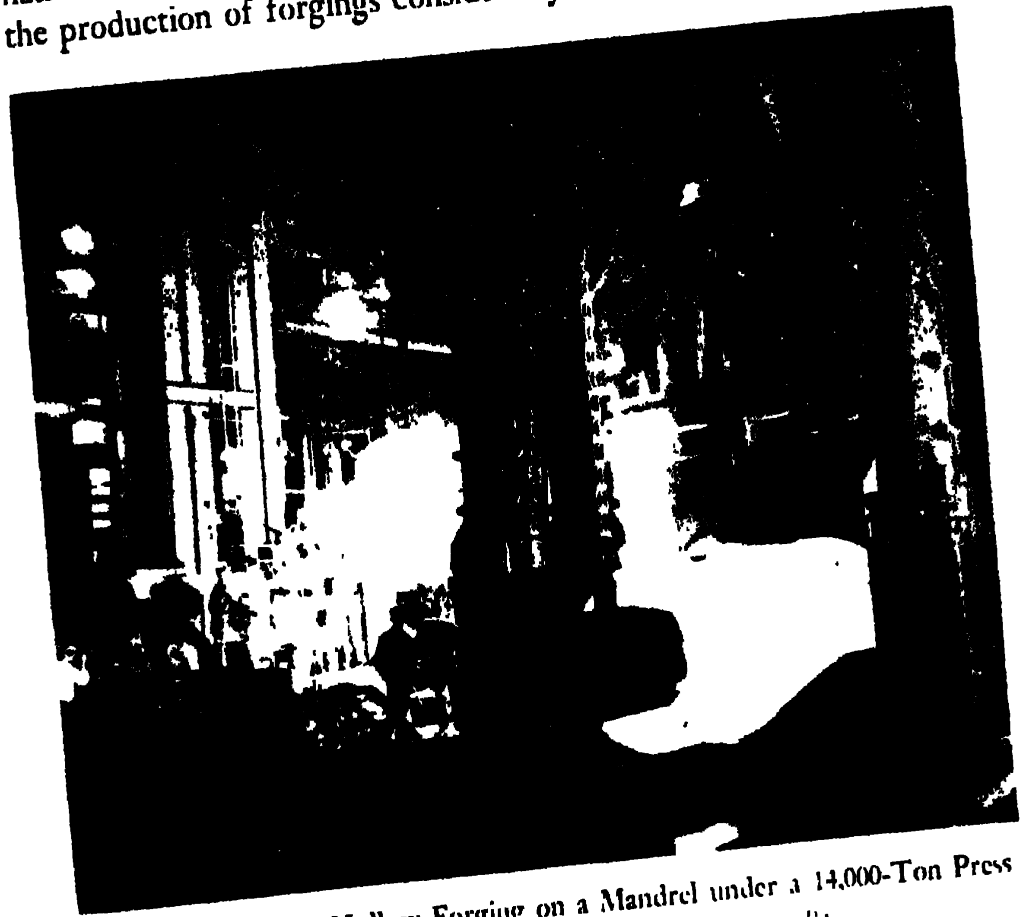

Fig. 9. Enlarging a Hollow Forging on a Mandrel under a 14,000-Ton Press

Courtesy of Bethlehem Steel Company, Bethlehem, Pa

Press Forging of Large Parts. Large hydraulic and mechanical forging presses may be employed more successfully than large forging hammers for forming very large parts. The main advantage of large, rising, hydraulic presses is that they cause less vibration than large forging hammers. Hydraulic presses exert squeezing pressure upon the work, whereas hammer pressure is that of impact. As previously stated, hydraulic presses range in size from less than 500 tons to over 15,000 tons. These values indicate the maximum pressures delivered by the presses.

Large steel ingots of round, square, or hexagonal sections, having a section area up to 40 square feet, may be forged down on the large hydraulic presses into products such as shafts for large motors and turbo-generators, turbine rotors, naval gun barrels, large shafts for ocean liners, large crankshafts, and die blocks for large forging dies. It is not uncommon for a 15,000-ton hydraulic press to forge large parts weighing as much as 200 tons—sometimes, even more. As previously stated, most modern hydraulic presses are operated by a series of pumps which compress oil or water in order to obtain the high hydraulic pressure required by the machine. Steam power is also successfully used for obtaining the required power, especially in the older-type machines. Fig. 8 shows the operation of drawing out a large shaft under a 1,000-ton forging press. Fig. 9 shows the operation of enlarging a hollow forging on a mandrel under a 14,000-ton forging press with rotator.

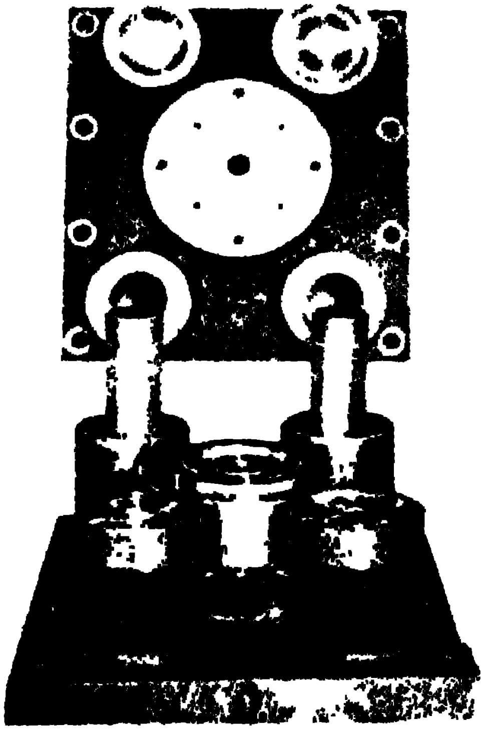

Fig 10. Set of Closed-Impression Dies Used to Press Forge a Typical Ring-Gear Blank

Courtesy of Drop Forging Association, Cleveland, Ohio

Press Forging of Small and Medium-Size Parts. Press forging operations can be applied in the production of small and medium-size parts of comparatively simple design by using closed-impression dies, only a single stroke of the ram being required. Most of the total work put in the forging press is transmitted to the forged metal, and the press reduction of the metal proper is rapid. Hence, a saving in labor cost is expected, and the products are found to possess greater accuracy than those produced by drop-forging operations. Forging presses may be of the mechanical or hydraulic type, and the products may be forgings of ferrous or nonferrous metals.

Fig. 10 shows a set of closed-impression dies for press forging a ring gear blank, and Fig. 11 shows the steps and operations performed in producing this forged product. Three forging operations are required to produce the gear blank. First, the heated metal is placed upright over the left die. In the next operation, the metal is compressed to fill the blocker die cavities completely, where the product assumes a rough approximation of its anticipated shape. In the final operation, the work is completed in the forming or finishing die. The upper and lower dies are provided with guide pins and bushings for proper alignment in operation.

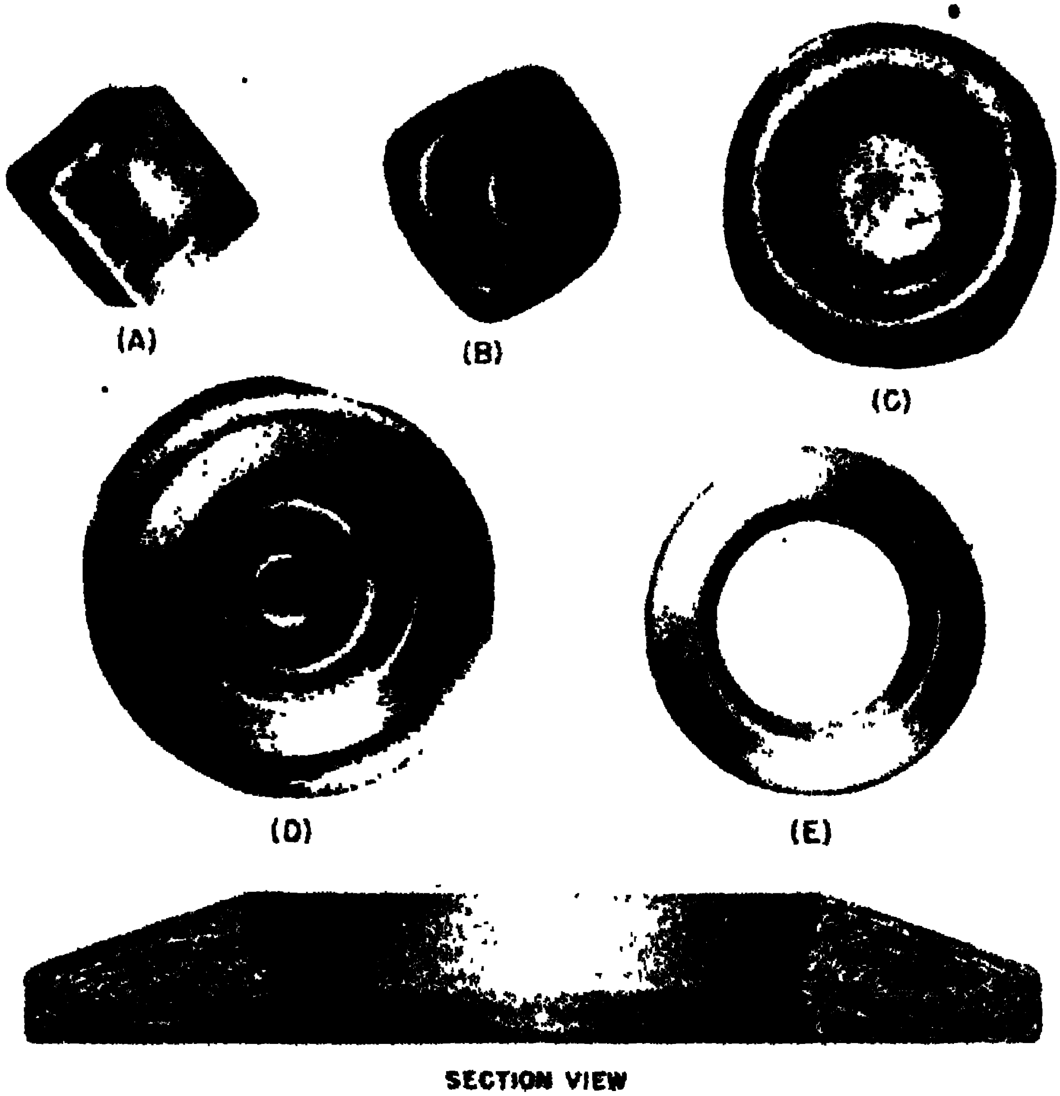

Fig. 11. Sequence of Operations Carried Out in Press Forging a Typical Ring-Gear Blank

Courtesy of Drop Forging Association, Cleveland, Ohio

The views of Fig. 11 illustrate the results of a sequence of operations carried out in press forging the ring gear blank. *A* shows the piece of steel or slug selected for the forging, which has been heated to the proper forging temperature preparatory to working. In the steps which follow, squeeze pressure is applied to the ends of the hot slug. *B* shows the effect of the first operation which upsets or "barrels" the metal, breaks off the scale, and prepares the piece for subsequent operations. *C* shows what has been accomplished after the piece has been compressed in the blocker die cavities, and *D* shows the result of the final forging operation. Now the piece is completely formed to the correct shape and size, but the flash is still present. At *E*, the finished forging, trimmed and ready for subsequent machining and finishing operations, is shown. The trimming of the flash and the punching out of the center hole is done on a trimming press with the aid of trimming dies. The section view at the bottom shows the fiber-like structure of the gear blank obtained in the press forging operation. The density and direction of the fiber flow lines have been controlled to provide toughness and shock resistance where they are most needed.

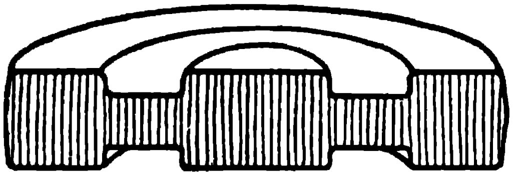

Fig. 12. Grain Structure of Gear Blank Machined from Bar Stock

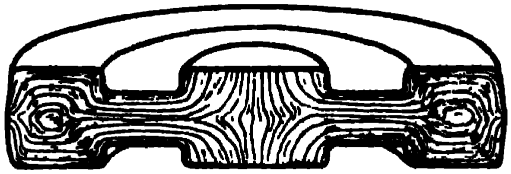

Fig. 13. Grain Structure of Forged Gear Blank

To further illustrate how forging fortifies the metallic strength and shock resisting qualities of a product, Figs. 12, 13, and 14 exhibit a contrast in the fiber characteristics of typical gear blanks produced by machining, on the one hand, and forging on the other. Fig. 12 shows the grain structure of a gear blank machined from bar stock. The grain flow is in one direction and is interrupted by the machining. The metal's maximum strength is not obtained, because the fibers are not interlocked. Fig. 13 shows the grain structure of a gear blank produced by forging in closed-impression dies. The fiber-like flow lines of this product are so gathered that all the gear teeth will be cut against a radically upset grain which will give uniform and maximum strength to each tooth. Fig. 14 shows a macro-etch of a cross section through a typical gear blank produced by forging. The flow-line structure of the metal that forging accomplishes is revealed by such a sectional view.

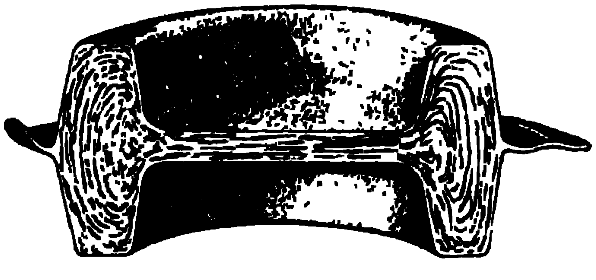

Fig. 14 Macro-Etch of Cross Section Through a Forged Gear Blank

A macro-etch is a machined and etched sample of a piece of metal that can be examined by the naked eye or under low magnification (seldom exceeding 10 diameters) for internal structure and condition.

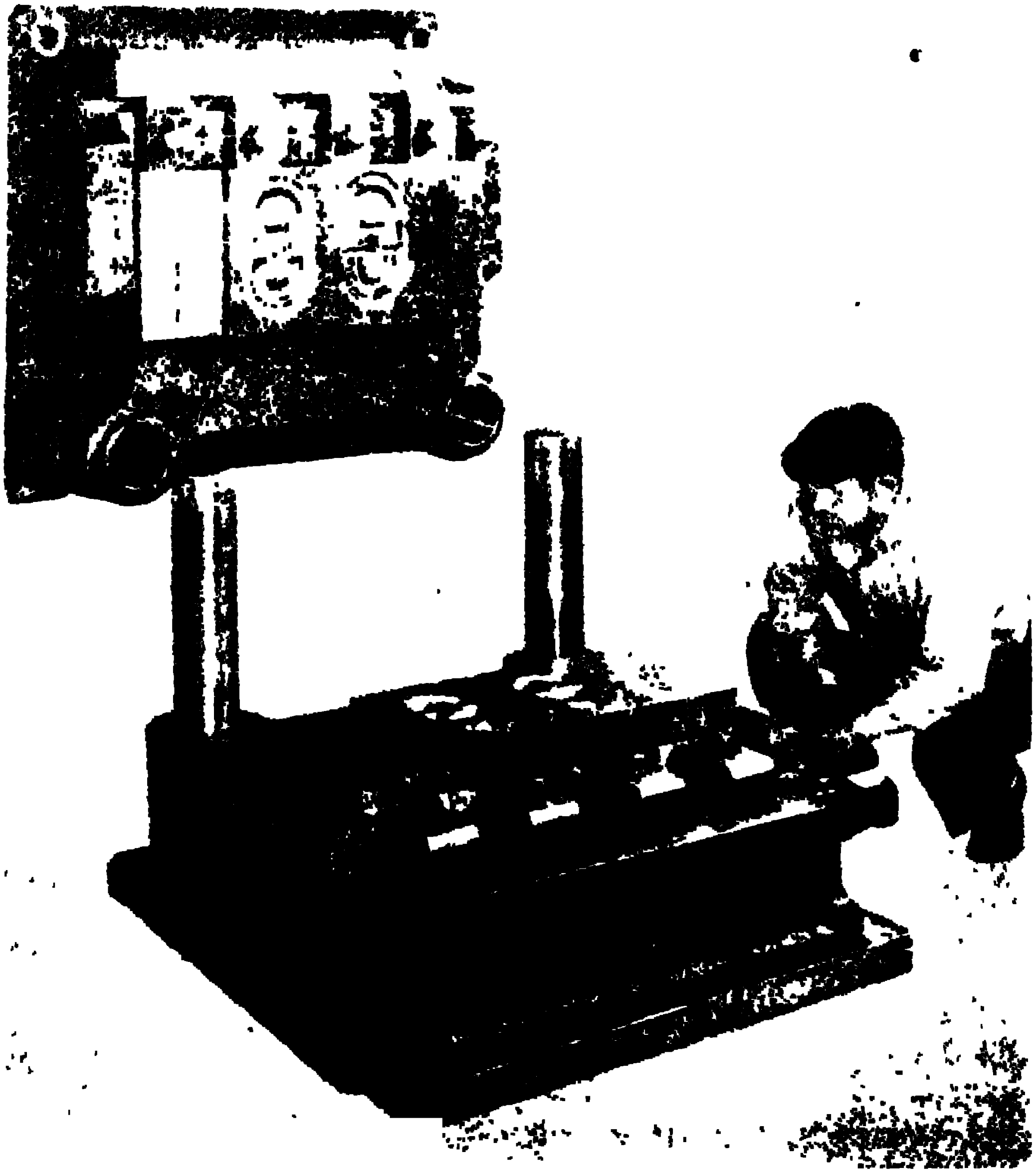

Fig. 15. Set of Impression Dies for Anchor Chain

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

Fig. 15 shows a set of impression dies for producing anchor chain. Small rectangular die blocks are held in the die bolsters by means of convenient toe clamps shown clearly at the front of the lower die bolster. The bolster is a plate mounted on top of the press table; it supports the die block. One pair of blocks is for edging and flattening the round-cornered square stock in order to dispose of scale. A second pair is for blocking, and a third pair is for finishing. The blank blocks at the right would accommodate additional operations if required.

Fig. 16 shows the sequence of operations carried out on these dies for producing the anchor chain. The hot slug is shown at the top of the figure. This slug is edged and flattened as shown in the next view lower. The blocking operation is shown in the next view, and the finishing operation is shown in the bottom view of the figure. An Ajax mechanical forging press was used for producing the anchor chain shown.

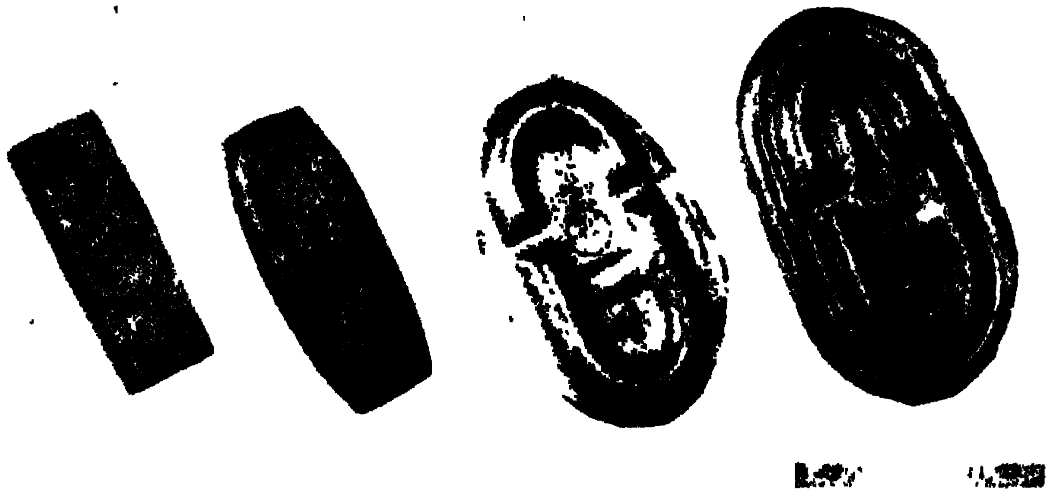

Fig 16. Sequence of Operations for Producing Anchor Chain

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

Press Forging on Production Basis. Symmetrical forgings may be formed successfully on a production basis by press forging. Examples are gear blanks, driving flanges and rock drills, and other similar products, which are press forged from blanks of round or round-cornered square stock that is sheared to length and then formed between suitable dies. The sequence of operations usually consists of a preliminary "barreling," which breaks off the scale, followed by "pancaking" or blocking, which displaces and locates the stock so that there will be minimum flow, flash, and abrasion to the dies in the final forming impressions. The finished forgings are produced with reasonably close dimensions and fairly smooth surfaces. There is very little chilled flash such as generally occurs in drop forgings because of the repeated finishing blows of the hammer. The objectionable flash may even be entirely avoided by entering the top die into the bottom impression so as to totally confine the forged stock. The accuracy of the forgings can be increased considerably by designing proper mechanical ejectors in both top and bottom impression dies. Ejector action makes it possible to reduce the amount of draft to the very minimum required, or to entirely eliminate it. Well-designed ejectors and the manner in which the press operates offer the possibility of handling many types of forgings without tongholds, a feature favorable to savings in costly material.

The die impressions employed in press forging the stock, either flatwise or transversely, are identical to those used in drop-forging operations. These impressions are the edger or fuller, bender, blocker, and finisher. Their arrangement depends upon the shape of the forging. In press forging machines, the ram stroke is constant. Therefore, the fuller must have ample cross-sectional area to accommodate the original bar stock without flash in order to prevent the possibility of folds or "cold shuts" in subsequent operations. Some forgings, owing to the nature of their design, do not require a fullering operation for metal distribution. In such a case, a preliminary flattening operation is substituted in order to dispose the formed scale.

The scale may also be eliminated through induction or controlled-atmosphere heating, hydraulic descaling, or preliminary scale-breaking operations (before the stock is prepared for heating to forging temperature). The ability to eliminate the scale in this fashion is of considerable importance in press-forging operations, since the heated stock is struck but once in each impression of the die. As stated before, a tonghold in these operations is frequently unnecessary because of the mechanical ejectors which release the forged piece from the die impressions. The transfer of the piece from one impression to the other is accomplished by the flash.

Blanks with pronounced variation in cross-section which need considerable drawing or fullering are not suitable to press forging because of the absence of a variable stroke in these machines. The steam drop hammer is usually recommended for forgings of this type, since it possesses a variability of hammer stroke. Some producers of complex-shape forgings by the press-forging technique obtain pre-rolled blanks or stock which has been previously fullered in trip or steam hammers for correct metal distribution, and then press forge them in closed-impression dies. The forging press can

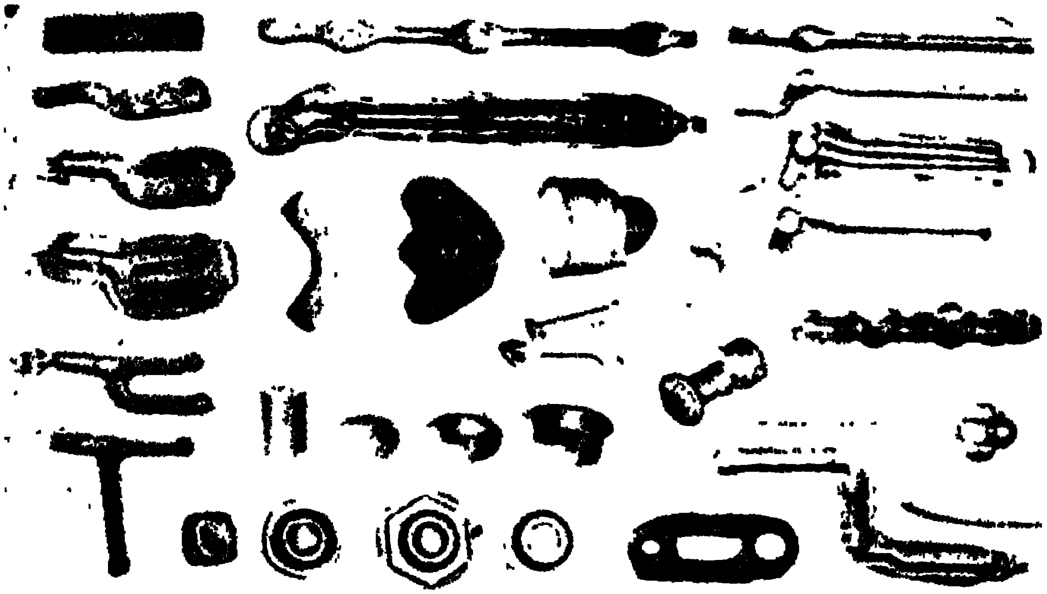

Fig. 17 Assortment of Press Forgings with Progressive Operations
Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

also be used to hot shear preliminary forging blanks of special analyses (special alloy steel, high-carbon tool steel) which cannot be sheared cold. The press can also be successfully employed for hot trimming high-carbon or alloy forgings already formed on the press, but not allowed to cool. Cooled forgings would be damaged by cold trimmings.

Fig. 18. Ajax Mechanical Forging Press
Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

Fig. 17 shows an assortment of press forgings with progressive operations. Fig. 18 shows one of the mechanical forging presses used for forming the assortment of forgings shown in Fig. 17. The press is equipped with a mechanically operated control ejector for top and bottom dies, and cam-operated lever ejectors for the bottom die. As stated before, these ejectors and the manner in which the press operates make it possible to handle many types of forgings without tonghold, thereby saving material.

Hot Press Forging of Nonferrous Parts Accurately to Size. Numerous nonferrous forgings, some of which are shown in Fig. 19, are produced by hot press-forging methods. The blanks or slugs are cut from an extruded bar or rod, and the heated stock is sufficiently plastic at forging temperature to fill the die impression completely at a single stroke. The forged parts are strong, dense, and will withstand relatively high pressures, since they are airtight, gastight, and watertight. These parts are smooth, accurate, and require little machining. Hot-pressed, nonferrous forgings are used for machines, engines, equipment, instruments, etc.

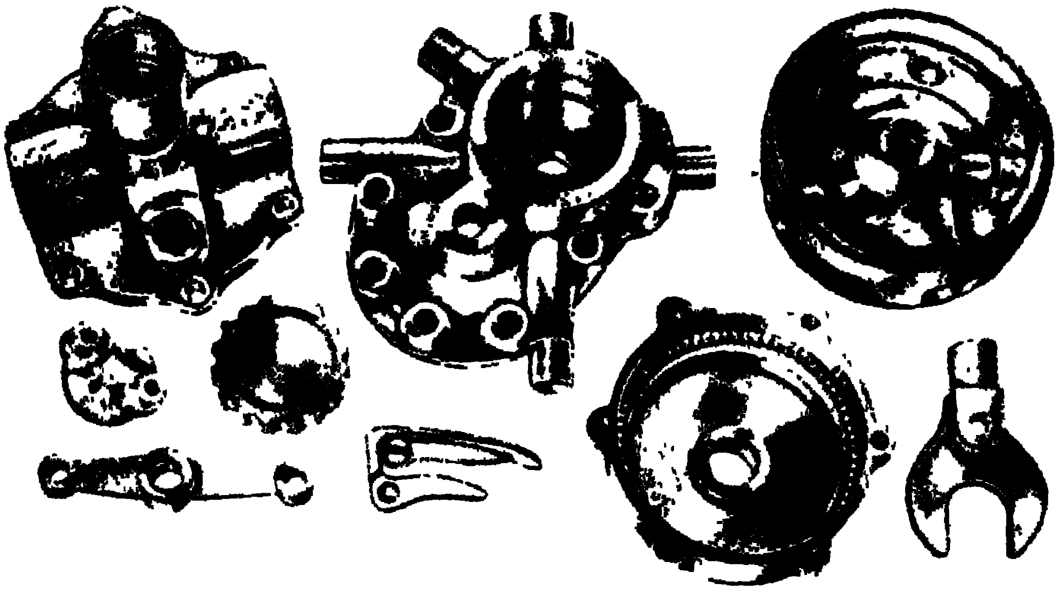

Fig. 19. Brass Hot-Pressed Forgings
Courtesy of The American Brass Company, Waterbury, Conn

The variety of parts that are press forged from nonferrous metals include those that are made of copper, copper-base alloys with their many compositions of brass and bronze, and light alloys of aluminum and magnesium. These various metals require *different forging temperatures* and certain modifications in forging techniques as compared with the methods used in forging steel.

Aluminum alloys are more difficult to forge than steel *because of the behavior of the metal at the forging temperature.* Nonferrous metals, such as aluminum alloys, are forged in the narrow low-temperature range from 700° to 900° F. A variation of 100° F. from the high limit would cause serious, perhaps permanent, damage, such as burning, to the heated stock which is ready for forging. Careful die design is extremely important for such forgings The dies must be made with provision for easy flow of the metal during the forging stages. Most of the nonferrous metals are not as ductile as steel at forging temperatures. Therefore, larger forging equipment is necessary for forming nonferrous forgings as compared with steel forgings of the same volume.

Nonferrous forgings produced from aluminum alloys are very strong, considering their extremely light weight. Magnesium forgings are even lighter than aluminum of similar volume, but have less

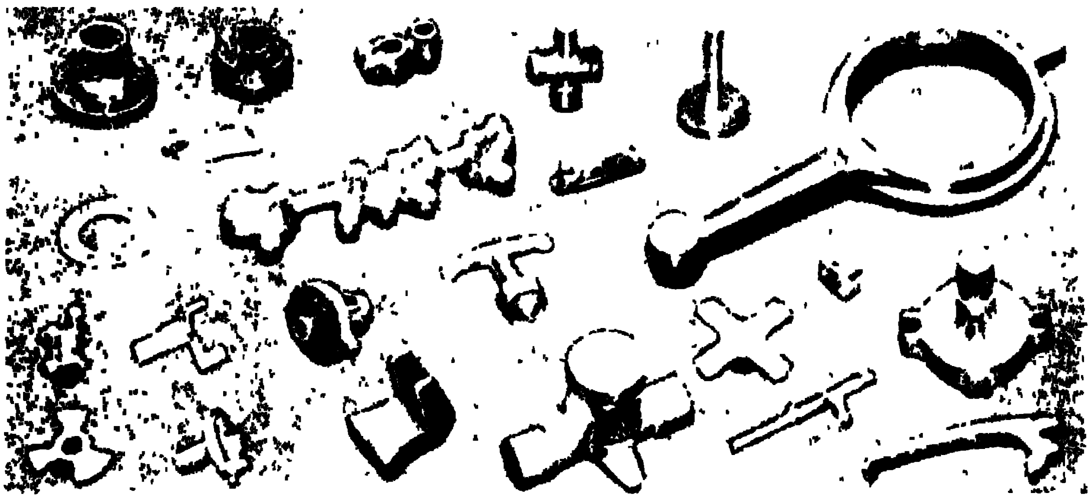

Fig. 20. Typical Brass Forgings

Courtesy of Revere Copper and Brass Incorporated, New York, N.Y.

strength than aluminum forgings of the same volume. Brass and bronze compositions are readily responsive to hot working, and are forged on a production basis in weights ranging from less than an ounce to over a hundred pounds. As a matter of fact, most of the nonferrous forging used in industry are within the above weight range. A large assortment of aircraft parts are forgings made of aluminum alloys. These parts are both drop forged and press forged. As forgings, they combine the required strength with extreme lightness. They weigh only a little more than one third as much as carbon steel, but have about the same strength as is found in low-carbon steel alloys.

Fig. 20 shows an assortment of Revere, die-pressed, nonferrous forgings. The heated metal is placed between dies, and tremendous pressures, delivered by high-power mechanical presses, force the metal into desired forms. Such an operation produces a fine, close, and "flowed" grain structure in these forgings, which greatly adds to their tensile strength (see Figs. 12, 13, and 14). These forgings are forged from extruded material. Thus, the metal has attained the greatest possible density through being worked twice under the high pressures employed in each operation. The result is the highest tensile strength, toughness, and fatigue resistance that it is possible to obtain in the metal or alloy. Fatigue resistance is resistance to repeated loads which tend to weaken the metal. Some alloys can be heat treated with good results. Parts made from those alloys are heat treated if the type of service to which they will be put demands it. The surfaces of these forgings are relatively smooth, and small design details (trademarks, model numbers, and names) can be held sharp and true. These forgings are also nonporous, and are impervious to oils, other liquids, and gases. Hence, they are desired for use in oil lines, chemical-plant equipment, and in refrigeration and other gas apparatus. Other uses of these forgings include service as plumbing goods, hardware, pressure fittings, valves, engine parts, electrical equipment, automotive parts, welding nozzles, contacts, wing nuts, anchor bolts, bushings, housings, and numerous highly stressed parts.[2]

Coining and Sizing of Machine Parts by Cold Press Forging. Coining and sizing are forming processes in which compression is applied to permit close tolerances and impart a smooth finish to surfaces of parts made of iron, steel, and other metals, where a small amount of flow is involved. In many cases, coining and sizing offer greater economy than cutting. Coining and sizing operations, of course, can be performed only on metals which have a fairly good range of ductility, such as malleable iron castings, steel drop forgings, aluminum, and other nonferrous metal parts that offer plastic flow under action of the press.

Forging presses, mechanical or hydraulic, are mostly employed for coining and sizing operations. Nevertheless, other machines, such as drop hammers, coin presses, and screw presses, may serve as suitable equipment. Selection of the press will depend upon the magnitude and severity of the operation. For example, a drop hammer may be used when the pressure is not excessive and where the metal will flow freely into the die. Mechanical and hydraulic forging presses, however, are preferred for operations of this kind, principally because of the ability of the press to utilize the greater portion of the operating cycle in actual compression of the metal, applying the remainder for the rapid closing as well as rapid opening of the dies.

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[2] Discussion of hot-press forging of nonferrous parts in immediately preceding paragraphs is adapted from *Technical Information on Revere Copper and Copper Alloys*, published by Revere Copper and Brass Incorporated, 4th ed., May, 1947.

Parts which furnish good examples of coined and sized products are connecting rods, brackets, levers, links, and numerous machine castings and forgings. The mechanical forging press is most widely used for these coining and sizing operations. High-speed press forging employs the fast squeeze-pressure method for accomplishing the desired results. In many parts the application of heavy pressure to a relatively small surface obtains a close tolerance—an action which often eliminates costly machining. A mechanical forging press designed for final forming to accurate dimensions by the process of cold or semihot coining and sizing is shown in Fig. 21. The compact one-piece design possesses a high degree of rigidity, and permits a speed of operation which makes the machine an efficient production unit.

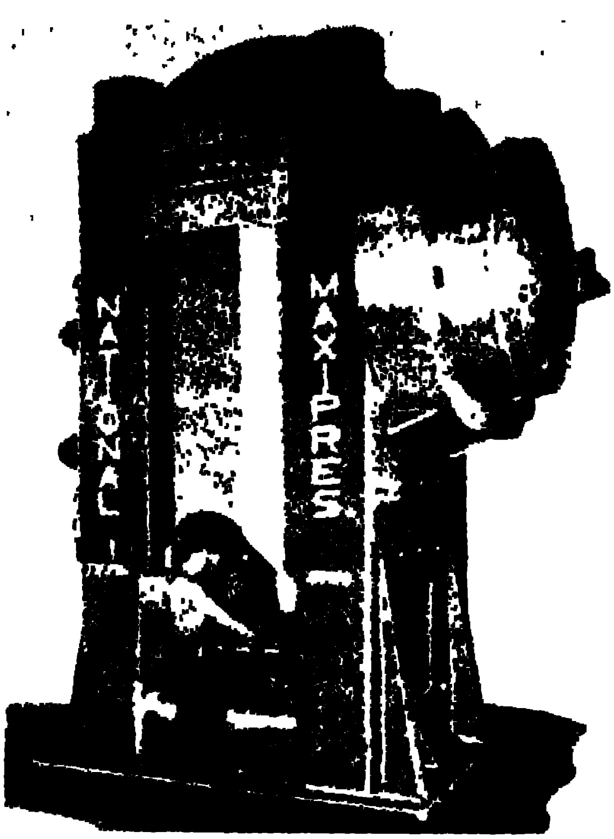


Fig. 21. Mechanical Forging Press for Final Forming

Courtesy of The National Machinery Company, Tiffin, Ohio

REVIEW QUESTIONS

1. What is the principle of press-forging operations?
2. What is the effect of press forging on the product?
3. What types of dies are used in press-forging operations?
4. Describe briefly the forging of steel die blocks, which are finally machined as required in order to be used as finished, closed-impression dies.
5. What alloy steel is recommended as a material for die blocks?
6. Name some of the products press-forged with open dies.

7. What two types of machines are mostly used in press forging?

8. Describe briefly the Ajax press, as shown in Fig. 6 of this chapter.

9. Describe briefly the hydraulic press, as shown in Fig. 7 of this chapter.

10. What is the main advantage of using large hydraulic presses in press forging large parts?

11. What is the range in sizes of hydraulic presses used in press forging?

12. Discuss the possibility of press-forging small and medium-size parts.

13. Describe briefly the sequence of operations carried out in press-forging a ring gear blank, as shown in Fig. 11 of this chapter.

14. What are some of the recommendations for press forging on a production basis?

15. How can the dimensional accuracy of press forgings be increased when they are manufactured on a production basis?

16. Name some recommendations for eliminating the scale on press forgings.

17. Name some of the practical applications of hot-pressed nonferrous forgings.

18. What advantages do hot-pressed nonferrous forgings offer in service?

19. List some recommendations for press-forging aluminum products.

20. Describe briefly the production of Revere die-pressed forgings.

21. Describe briefly the operations of coining and sizing of parts by cold-press forging.

22. What kind of presses are used for the operations mentioned in question 21?

CHAPTER VIII

Machine or Upset Forging

Upset-Forging Method of Hot Working Steel. Forgings produced by this method are formed by squeeze pressure instead of by impact force as in the drop hammer. The forging machines used for upsetting the metal are designed to furnish the necessary pressure. The closed-impression dies that are used with the machines are designed to grip the metal, as well as to carry impressions into which the hot plastic metal is pushed by a punch held in that portion of the machine which is called the *header ram*.

The operation of upset forging consists of inserting a heated bar of stock between the movable and stationary halves of the set of dies, against a gage which permits a suitable amount of metal to project beyond the gripping portion of the dies for upsetting in the impression cavity by the header ram.

Machine or upset forging, similar to drop forging, may be completed in more than one step in order to develop the finished shape The heated bar, upon completion of the first step in one impression of the dies (where preliminary simple forming takes place), is moved along to succeeding steps in other die impressions until all shaping has been completed. Numerous forgings may be so simple in design that only one step in a single impression of the dies is required for completion of the product. Other forgings of complex shape may require a larger number of steps—even as many as six for the more difficult forgings. While drop forgings and press forgings often need to be trimmed because of flash, most upset forgings do not require this operation.

Machine or upset forgings range in weight from one ounce to over 500 pounds and, similar to the parts produced by the other forging methods, the continuity of the fiber structure is maintained while the metal is being compacted and shaped. Frequently, the forging machine may be utilized in combination with the drop hammer and forging press to produce a large variety of forged products economically. A greater manufacturing cost would be entailed if only a single forging method were employed.

Upset-Forging Machines. The first forging machines were designed for upsetting or gathering metal to form rivet heads and bolt heads. The successful accomplishment of this objective led to broad development of machines able to perform a large variety of upset forging work and other work involving not only upsetting operations but also metal displacement operations.

The upset-forging machine is basically a horizontal press designed for double action. Fig. 1 shows an upsetting machine of conventional design in operation. In a heavy cast-steel body, a stationary die and a moving die grip the work, while a heading or upsetting tool moves against the stock, forming it into the cavities in the dies. Upon com-

Fig. 1. Ajax Air-Clutch Forging Machine

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

pletion of the operation, the slide holding the heading tool recedes and the dies are opened. In the event that the work requires more than one pass, a number of cavities or impressions shaped in the dies to conform with the contour of the work are included in one set of dies. The bar of stock is moved to each succeeding position in order to be ready for the next pass.

The machine shown in Fig. 1 is an Ajax 2-inch air-clutch forging machine. The air clutch is a direct, pneumatically operated, multiple-disk, friction clutch. The easy tripping and instantaneous starting of the clutch eases the work of the operator, and makes possible the completion of a forging in a single heat without subsequent reheating after preliminary upsetting.

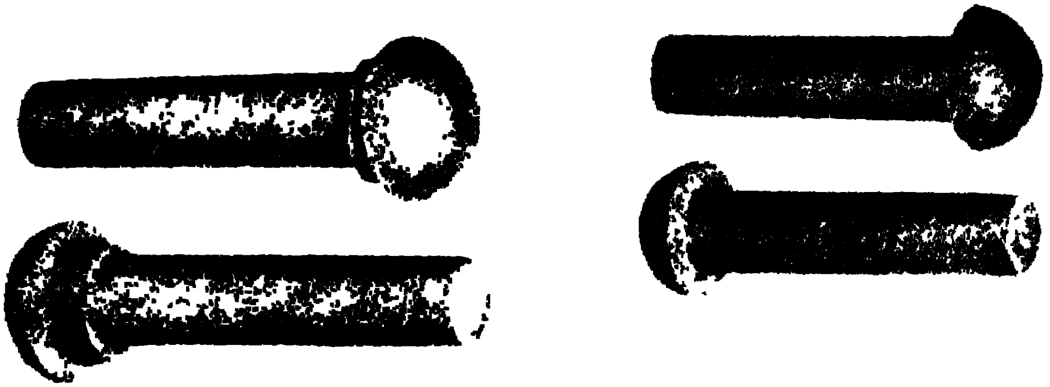


Fig. 2 Round-Head and Oval-Head Bolts Without Flash

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

Blanks of correct diameter may be cold-sheared to length and tong-fed to the machine. This method is used to produce hexagon or square-head machine bolts. The blank is heated only on the end to be headed. It is then handled with tongs and inserted into the throat of the machine through an open or U-type backing plate. The head is upset in the lower die groove first; then the piece is transferred to the upper groove of the dies where the square or hexagon side of the head is formed accurately in the die impressions by the crowning tool. This latter tool flattens the crown. The piece is generally struck two or three times in the second impression, and is turned between blows to fill out the corners as sharply as possible. The tooling may be so designed that no flash is formed, either between the gripper dies, i.e., the dies that hold the stock, or at the face of the header. In such case, no flash trimming is necessary.

A header machine may be equipped with a bar feed, i.e., a mechanism feeding the bar toward the dies, and an automatic ejector of finished workpieces for volume production. This arrangement is used to produce comparatively short rivets, carriage bolts, and track bolts where the head can be properly formed without flash in a single blow. Samples of such bolts are shown in Fig. 2. It is also used to produce square and hexagon head bolts with washer-shaped flash about $1/16''$ thick under the head as shown in Fig. 3. The flash can be trimmed cold in a trimming press later.

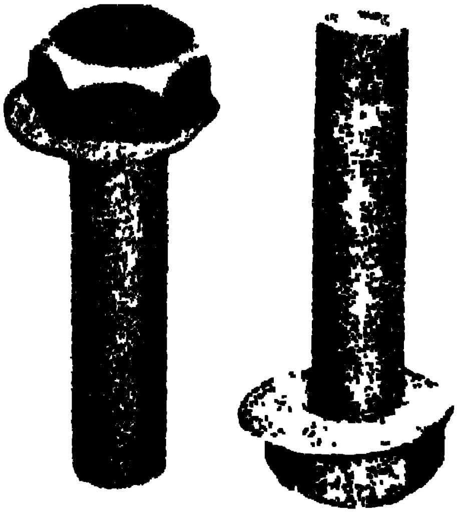


Fig. 3 Hexagon-Head Bolts with Washer-Shaped Flash

Courtesy of [illegible] Manufacturing Company Cleveland, Ohio

For the bar feed method, bar stock approximately ten feet long is heated for a length of two or three feet and fed through the feed part in the backing plate against the stock gage as shown in Fig. 4. This illustration shows a view looking into the die space of a 2-inch machine fitted for bar feed operation. The stock gage can be seen in the foreground. In closing, the moving die shears off a blank of the required length and grips it against the stationary die where it is headed. As the dies open, the piece is automatically ejected. This operation is repeated until the heated portion of the bar is used up. A completed piece is produced with each revolution of the machine.

Since the length of the dies determines the length of the bolt or rivet under the head, different length dies are required for each different shank length. The dies generally have two grooves in each of the opposite faces, or four grooves in all, as shown in Fig. 5. Four different diameters of bar stock may be formed in these four grooves. When the grooves become worn, they can be redressed by machining back the working faces of the dies (reducing the length of the grooves), since most of the wear occurs at the end of the grooves where the head is formed and the bar is sheared. The cutter is also provided with two working faces. The heading tools are cylindrical and are clamped in a single-station toolholder, as shown in Fig. 5, in order to permit adjustment beyond that provided by simply inserting hardened washers to make up for shortening during redressing.

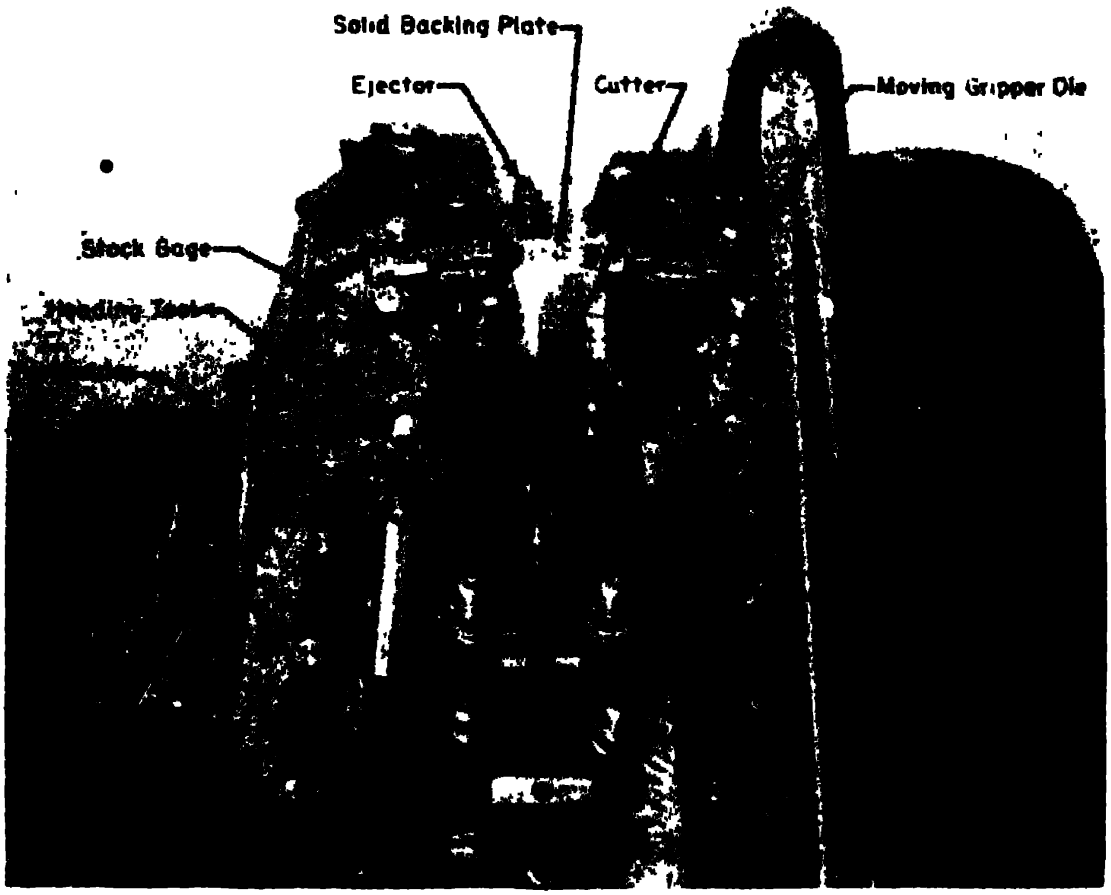


Fig 4 View into Die Space of a 2-Inch Forging Machine
Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

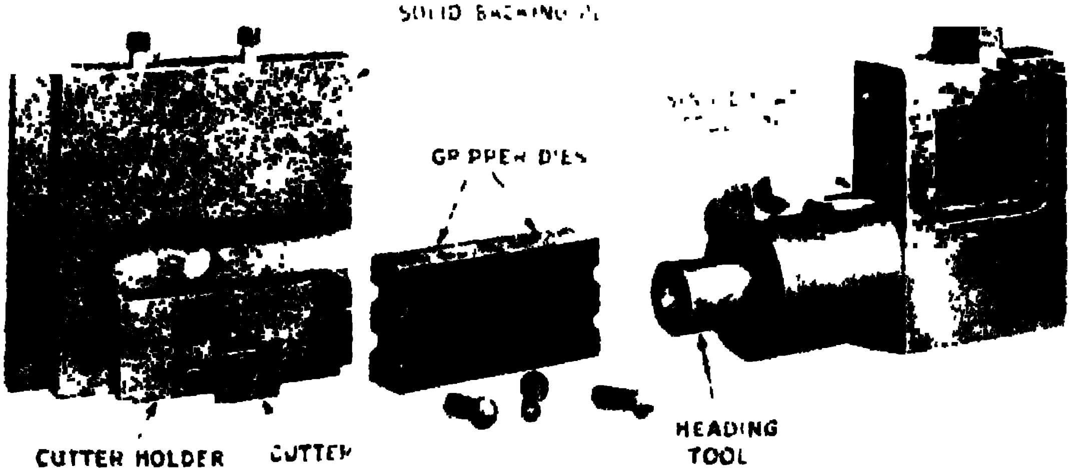


Fig. 5. Backing Plate, Cutter, Dies, Tool, and Toolholder of Forging Machine with Bar Feed and Automatic Ejector
Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

Upset Forging Dies and Tools. Upset forging is carried out in well-fitted dies without draft, i.e., without taper allowance to facilitate easy withdrawal of the work-piece. In many instances, no flash is formed. Straight holes may be hot-pierced, and they require little subsequent machining. If dies are properly designed, long bars may be successfully upset without buckling. Fig. 6 demonstrates that heated stock measuring six diameters in length can be upset if the recessed dies are properly designed.

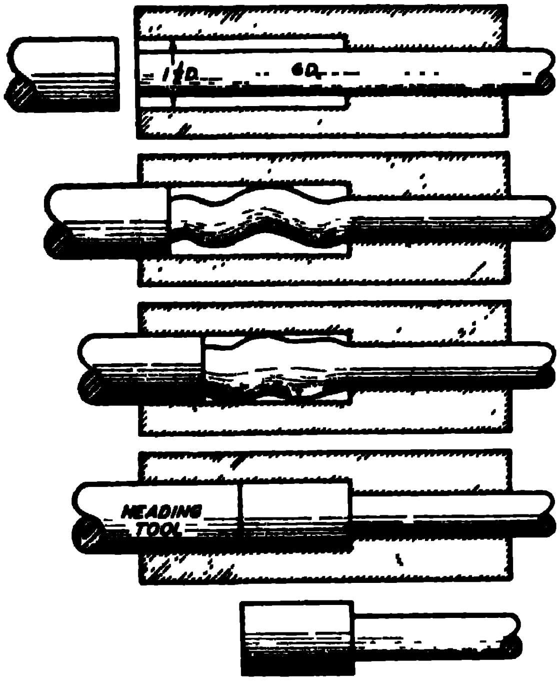


Fig. 6. Stock That Is Six Diameters in Length Can Be Upset in Properly Designed Dies

In machine forging, the heated bar of steel is upset by successive forming operations. These operations increase the bar's diameter and shorten its original multiple length until, in the final operation, the original multiple length is reduced or shortened to conform to the shape of the forging desired. Machine forging is not limited to simple gripping and beading operations. The transverse action of the moving die and the longitudinal action of the heading tool are available for forging in both directions, either separately or simultaneously. The die motion can be used for swaging, bending, shearing, punching, and trimming, in addition to gripping. The heading tools can be used for punching, internal displacement, extrusion, slotting, trimming, bending, and other operations, in addition to upsetting.

The cavities representing the shape of the product are formed by the two dies, and the heading tools are designed to upset the metal until it fills the die cavities, as shown in Fig. 7 Frequently, the working stock is totally confined in the die cavities during forging. It is subjected to a hydrostatic-like pressure, causing the metal to completely fill the impressions. Thus, a great variety of shapes can be forged. Cluster gears, worm gears, pinions of many types, shafts, axle housings, axles, drawbars, valve stems, fan spindles, steering worms, radius rods, radial-engine aircraft cylinders, and hundreds of other parts are now being formed by the machine, or upset, forging method.

Fig. 7 shows, at the top, a set of dies and punches for production of a cluster gear in the forging machine or upsetter. The sequence

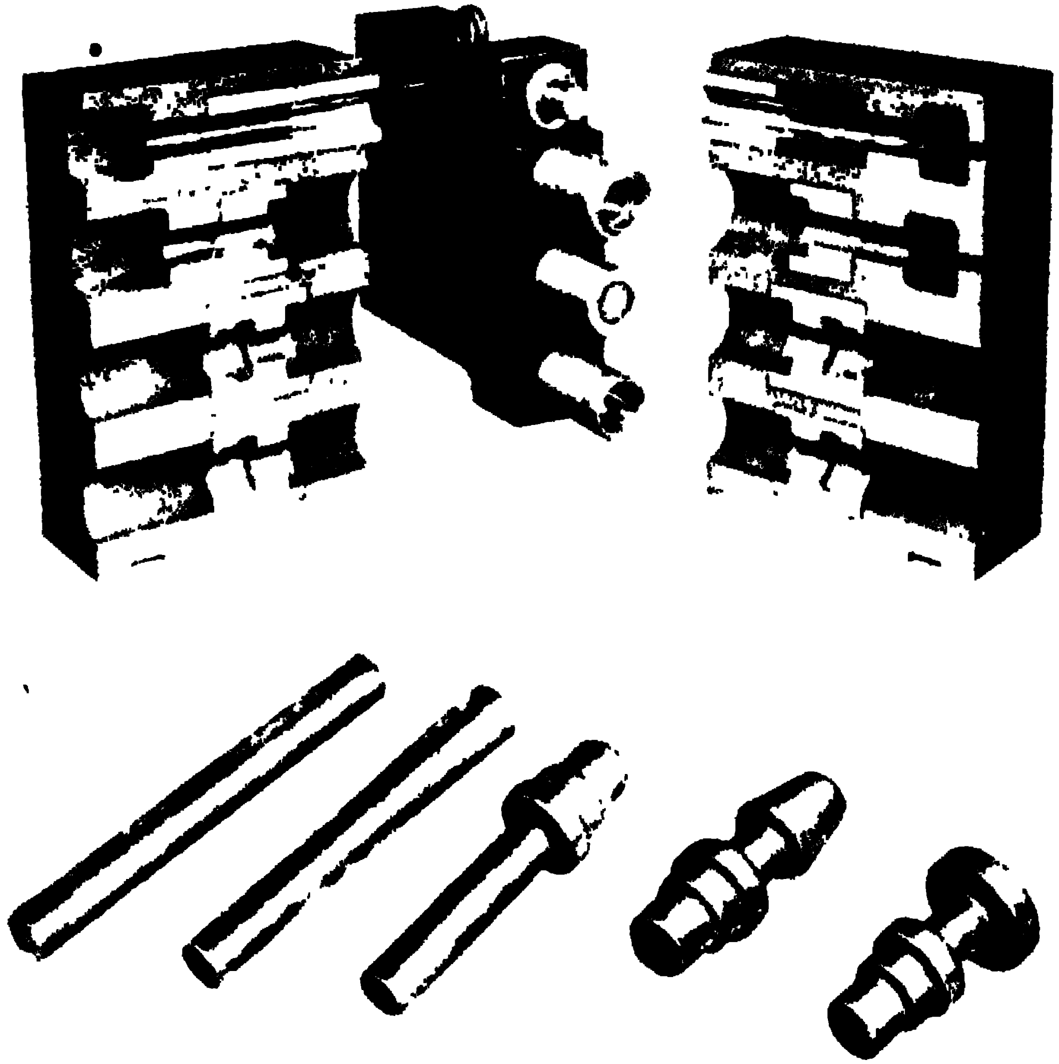


Fig. 7 Set of Dies and Operations for Forging a Cluster Gear
Courtesy of Drop Forging Association, Cleveland, Ohio

of operations is shown at the bottom of the figure in the following order from left to right: (1) The bar of stock is heated to the correct forging temperature. (2) The end of the stock is upset in the upper position of the dies to gather stock for one end of the gear. (3) The smaller end of the cluster gear is finish-formed in the upper center position of the dies. (4) The opposite end of the bar is upset in the lower position of the die to gather stock for the remainder of the cluster gear, while the bar is gripped on the partly finished end.

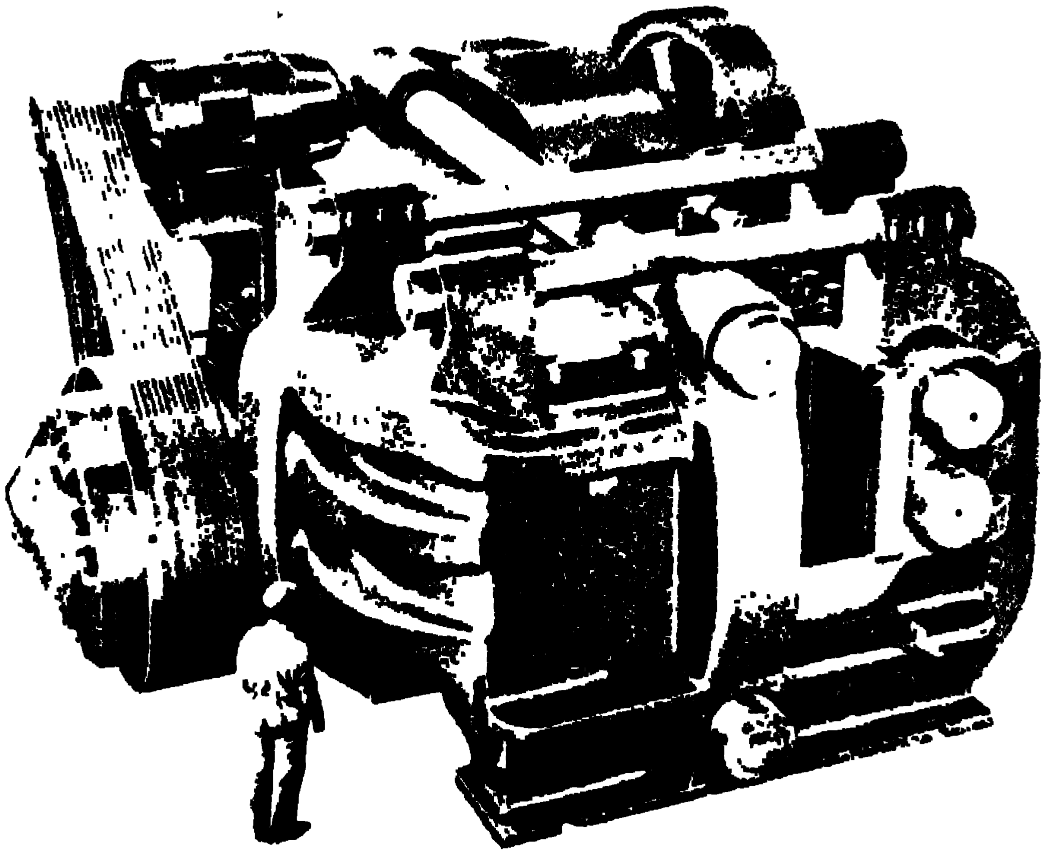


Fig. 8 National High-Duty Forging Machine
Courtesy of The National Machinery Company, Tiffin, Ohio

(5) In the last operation, the finished gear is produced by another upsetting and forming of the large end portion of the stock in the lower center position of the dies.

Hot working metal by the upset-forging process utilizes to the utmost the physical properties inherent in the steel, and develops maximum uniform strength and durability throughout the structure of the forging. For a successful accomplishment of desired results, a thorough understanding of the upset process and proper design of dies and other required tooling are essential. The laws governing the deformation of plastic metal by the upset process must be well understood, especially those laws which govern the amount of stock that may be gathered or upset in each forging operation without objectionable buckling of the flow lines. If correct upset-forging technique is employed for gathering the metal, which can be accomplished by proper die design, a controlled grain flow and development of an ideal dense fiber structure throughout the forging will result, as shown in illustrations of Chapters VII and VIII. Forgings produced by upsetting usually conform closely to the contour of the finished product. They have very little or no draft at all. Thus, economies in steel saving and machining time are achieved.

The upset-forging method is also employed to a considerable extent for producing a variety of pierced forgings. Internal-recessed or deep-cavity forgings are produced most easily by the progressive-displacing method, i.e., gradual displacement of metal from step to step. In this method, the metal from the interior of the full-length blank is progressively displaced to the outside of the die cavity.

Examples of Modern Hot-Upset-Forging Practice. An almost endless variety of close-limit, accurate, machine forgings can be produced on modern forging machines with marked economy of material consumption and machining attention. Fig. 8 shows a National high-duty forging machine which has been developed for volume production of a wide variety of work. This machine weighs 500,000

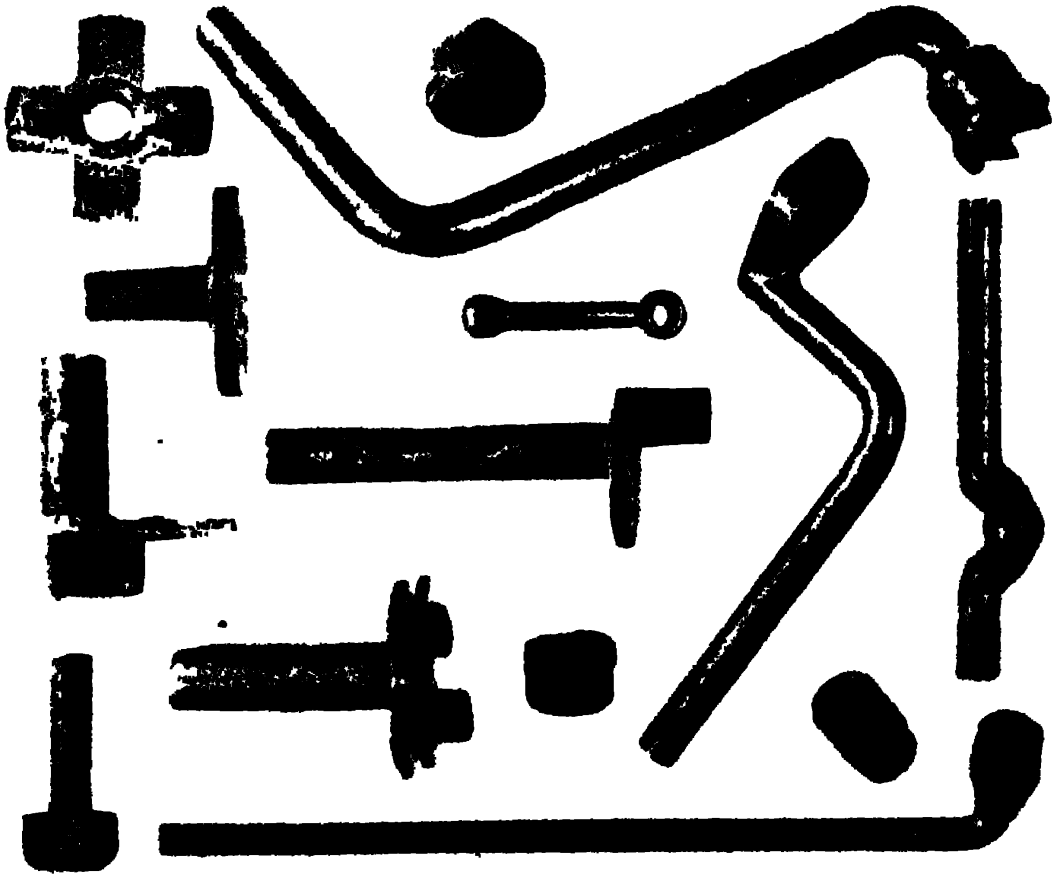


Fig. 9. Variety of Forgings Produced on National High-Duty Forging Machines

Courtesy of The National Machinery Company, Tiffin, Ohio

pounds. With the aid of modern well-designed machines, the progressive forge shop is today successfully producing parts which formerly were considered too difficult or costly to make. Intricate shapes, unequal cross sections, irregular contours, and deep holes no longer are beyond the field of machine forging. No longer is it necessary to tolerate an excess of metal that would have to be machined away.

Fig. 9 shows a variety of forgings produced on National high-duty forging machines. Such work as pierced drag links, deep-socket wrenches, large-size valve forgings, large head bolts made on roll-thread stock, elevator bolts, and many other products of intricate shape, as well as those requiring a large amount of stock for forming the proper shape, can now be successfully handled on a production basis.

Such products are machine forged with comparative ease on the modern upsetters designed for producing such parts with sufficient accuracy on a large volume production basis. The machines have sufficient rigidity to withstand the heavy punishment imposed upon

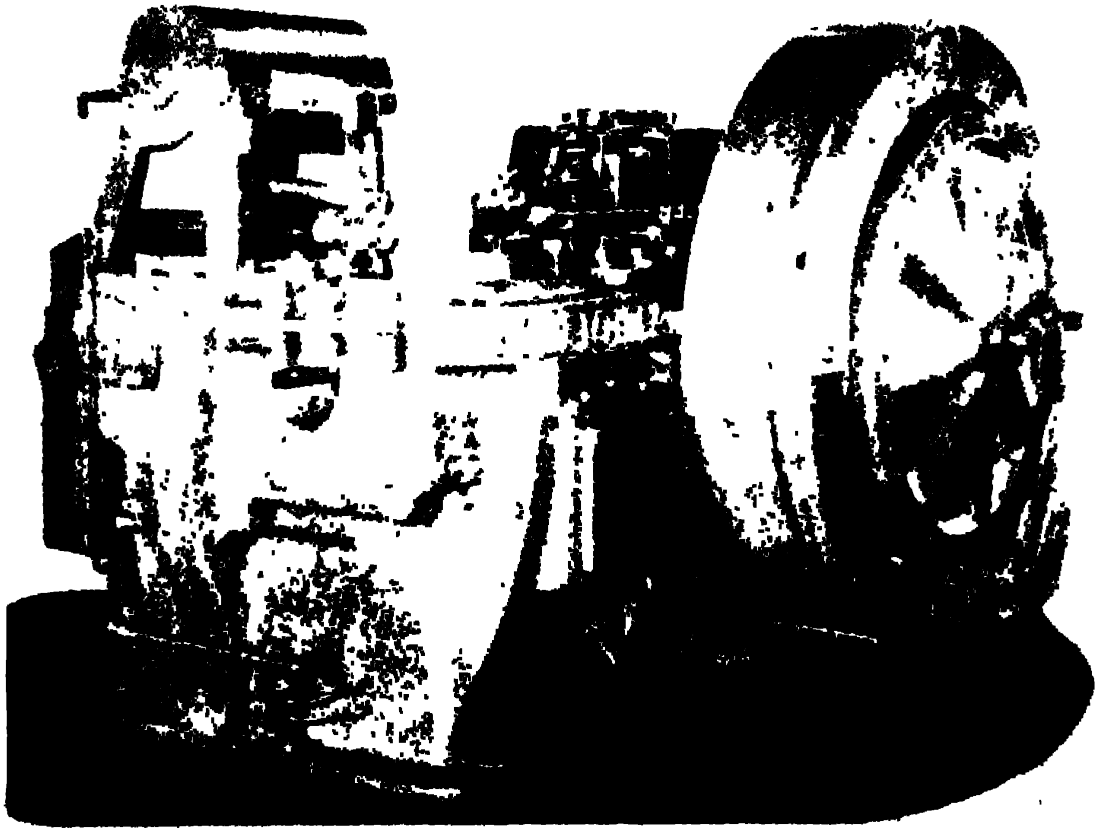


Fig. 10 National No. 1 Automatic Tong Feed Forging Machine

Courtesy of The National Machinery Company, Tiffin, Ohio

them. The short, compact bed-frame, which reduces spring to a minimum; the wedge-operated gripping slide; the over-arm heading slide; and the bolster plate; all of these features which insure such positive and accurate alignment of the heading tools with the gripping die impressions, are built into forging machines of modern design, and make possible their successful production of difficult products.

Automatic-Feed Upset-Forging Machines. New machines have been developed to make a wide range of upset forgings from bar stock. Fig. 10 shows a National automatic-tong-feed forging machine. The stock is previously sheared to length, heated in an automatic furnace, and delivered into the feed chute of this machine. On each stroke, a blank is introduced into the top impression, and the automatic tongs feed the blanks down through the dies. A forging is completed on each stroke of the machine, regardless of the number of passes. The speed of the machine is 90 strokes per minute. It is driven by a 7½ h p. motor; the speed of the motor is 720 r.p.m.

Fig. 11 shows a view looking into the die box of a National automatic-tong-feed forging machine. This view shows the automatic feeding tongs. The blanks are delivered into the chute from an automatic furnace. A plunger pushes a blank into the dies, and the automatic tongs carry it down through the various impressions. On each stroke a new blank is introduced into the dies, and an operation is performed in each stage simultaneously. In this manner, a complete forging is produced on each stroke of the machine, regardless of the number of operations required to make the forging.

Fig. 11. Die Box of Automatic Tong Feed Forging Machine

Courtesy of The National Machinery Company, Tiffin, Ohio

Effect of Temperature in Upset Forging. The temperature of the metal suitable to successful upsetting operations depends upon a number of factors. Included among these are the shape and size of the forging, the kind of steel used for the product, the ease with which the heated metal fills the die cavities, the finish required, and other factors characteristic to the particular needs of the product. In the event that the product requires many operational steps for its completion, the temperature to which the original stock is heated must be considerably higher than the temperature required for comparatively simple products. Many simple parts, such as bolts, rivets, and plain links, may be upset in one or very few steps. The preheating temperature for these parts is quite low, generally ranging from 1300° to 1500° F.

It is desirable to keep the preheat temperature of steel as low as possible, as indicated above, in order to prevent excessive scaling. If the forged products are simple in design, and very few operational steps are needed for their completion, the preheat or forging temperature may be below 1500° F. for best results. However, numerous forgings of complex shape and large size require preheat temperatures well above this figure. Modern furnaces, which are properly designed and equipped with instruments controlling the furnace atmosphere, may be successfully employed to accommodate the latter type of forgings. In the case of nonferrous metals, the forging temperatures must be considerably lower than those required for steel. Furthermore, the heating range within which the nonferrous metals must be held are much narrower than those recommended for steel.

Suitable forging temperatures for upsetting steel may vary from 1300° to 2200° F. The temperatures for copper-base alloys may vary from 1000° to 1600° F., and for aluminum alloys from 800° to 1000° F. The best forging temperatures are usually determined by analyzing all the factors involved in the particular product, and by experimenting with several test heats before establishing a production run. The *Metals Handbook*, published in 1948 by the American Society for Metals, provides recommended forging temperatures for many ferrous and nonferrous metals.

Cold Forging or Cold Heading. This is a metal upsetting process carried out on machines specially designed for rapid production of large quantities of small parts from wire stock. This process was first introduced for the cold forming of heads on rivets, bolts, and screws. At present, it has wide industrial applications in the manufacture of bolts, screws, rivets, links, pins, nails, and many other small machine parts that can be conveniently produced from continuous wire stock. This process is also well suited to the production of small steel balls for use as ball bearings and rollers for use as roller bearings.

The machine used in this process is similar in principle to the hot-forging machine previously described. Heated metal is upset to required shapes with the aid of suitable dies. In the cold-heading machine, wire is supplied in reels, and is cut to the length required It is then carried automatically through the upsetting or forming operations in properly designed and precisely positioned sets of dies This method of manufacture is applied in large-volume production. Machines properly set up may reach a production of as many as 300 small parts a minute, without requiring constant attention. Consequently, one operator is able to attend to a battery of machines. The operator's duties consist of supplying stock to each of the machines as needed and making periodic inspections.

The power required to form parts by this process is very great. Therefore, the wire diameter usually employed in cold heading does not often exceed 1 inch Fig. 12 shows a typical cold-heading machine used to produce small pieces, such as bolts and nails The rolls feeding the stock to the die block are shown at the left of the figure.

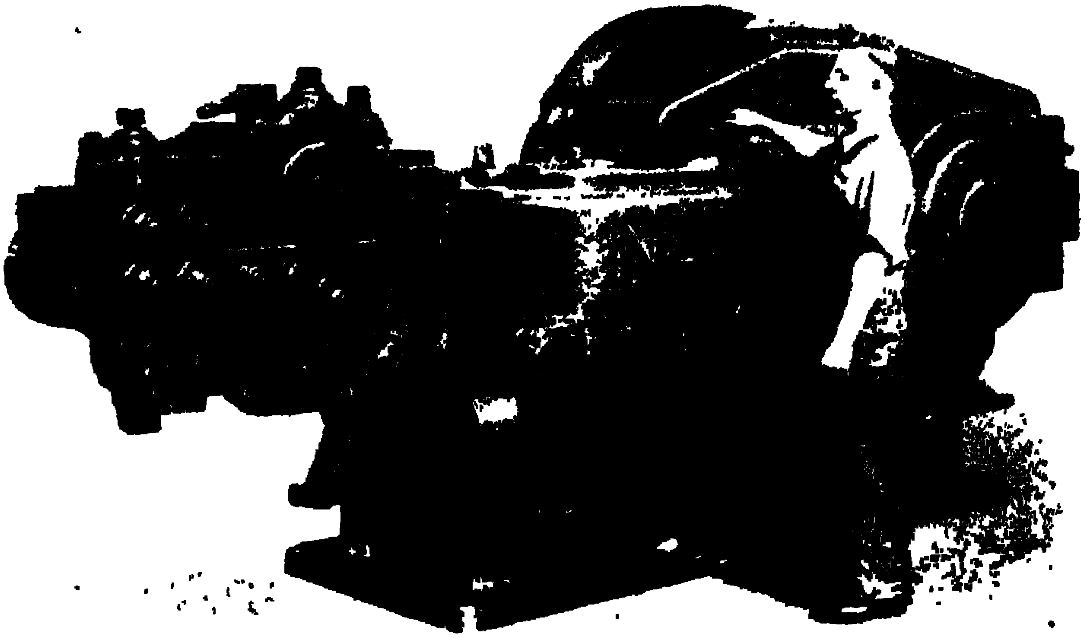


Fig. 12 Double-Blow ⅝-Inch Cold-Heading Machine

Courtesy of The National Machinery Company, Tiffin, Ohio

Operational Steps in Making a Typical Cold-Headed Part. The sequence of operations in making a typical part are as follows:

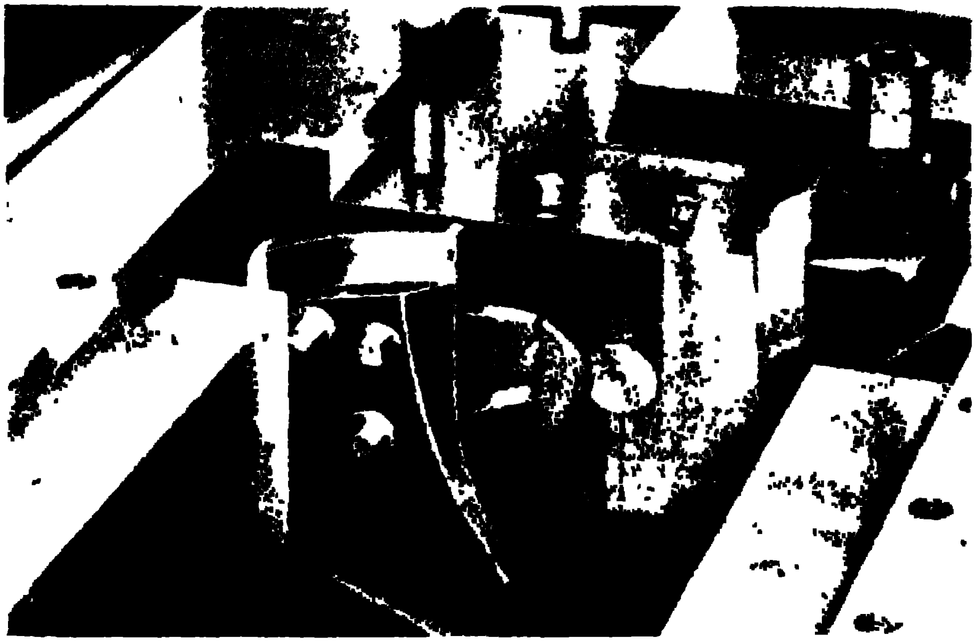


Fig. 13. Machine Fingers Gripping Portion of Rod Extending through Cutoff Die Before Shearing to Proper Length

Courtesy of The National Machinery Company, Tiffin, Ohio

The wire or rod is fed from the reel by the feed rolls, and is pushed through the cutoff die to a set stop (a gage stop arranged in the re-

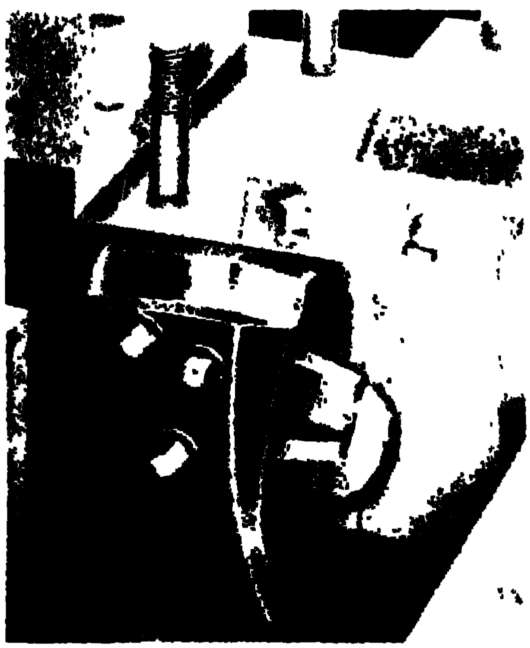


Fig. 14. Severed Portion of Rod Being Carried by Fingers to Upsetting Die Holder

Courtesy of The National Machinery Company, Tiffin, Ohio

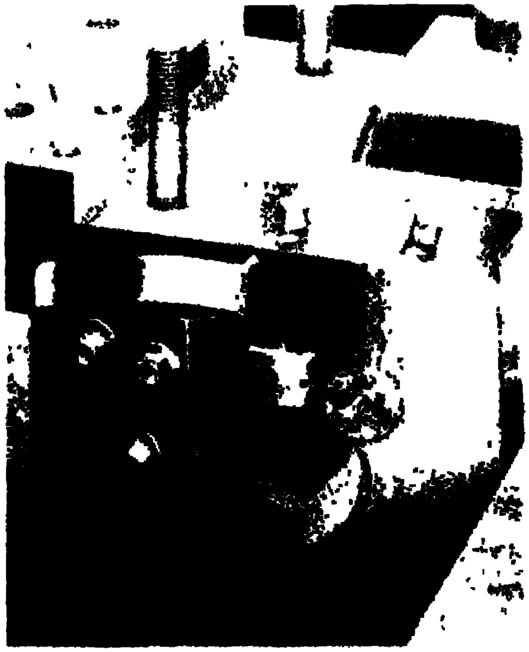


Fig. 15. Blank Shown Here Is Positioned Properly in Upsetting Die Holder

Courtesy of The National Machinery Company, Tiffin, Ohio

quired position with reference to the work piece). Fig. 13 shows a portion of the stock rod extending through the die. While being held by the fingers, the rod is sheared to a definite length, and is then carried over to the upsetting die holder as shown in Fig. 14.

The severed length of rod is pushed into the upsetting die to a calculated depth. A single die, or a set of moving dies, comes forward to upset and form a head of the proper shape on a bolt, rivet, or other machine part. Fig. 15 shows a blank positioned properly in the upsetting die holder. In Fig. 16, the operational steps in making a typical cold-headed part on a double-flow header are indicated. The cutoff blank is seen at the left, the cone-shaped blank at the center, and the finished blank at the right.

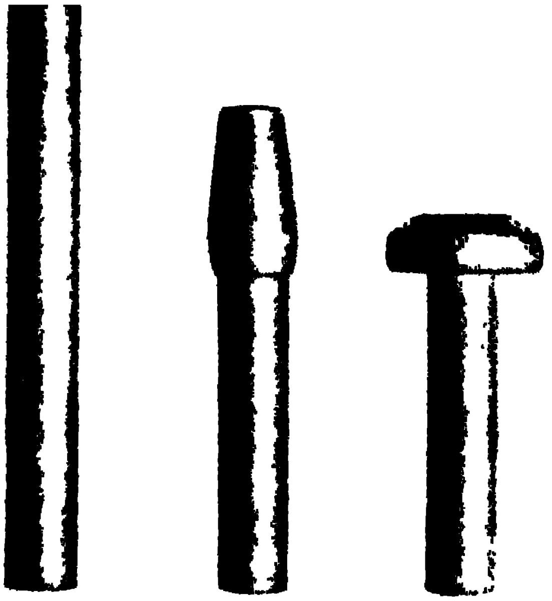


Fig. 16. Operational Steps in the Making of a Typical, Cold-Headed Part

Courtesy of The National Machinery Company, Tiffin, Ohio

Cold Swaging. This operation is similar to cold forming, and consists of forming metals not fully confined in the die grooves by subjecting them to a series of blows between dies. A typical operation of cold swaging is the rotary reduction or tapering of the cross section of a solid rod or tube as shown in Fig. 17.

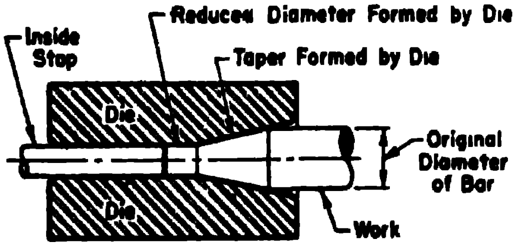


Fig. 17. Reduction and Tapering of Cross Section of a Solid Rod

In a swaging operation, the metal is subjected to severe, cold working on all sides by the dies, which are supported in a slot cut in the face of a rapidly revolving spindle. The spindle is contained in a housing in which a number of hardened steel rolls are arranged. When the spindle revolves, the steel dies pass successively between pairs of opposite rolls that force the dies together, thus squeezing the work and reducing it to the required shape and size. A rotary swaging machine is shown in

Fig. 18, and sectional views of open and closed die positions are shown in the two drawings of Fig. 19.

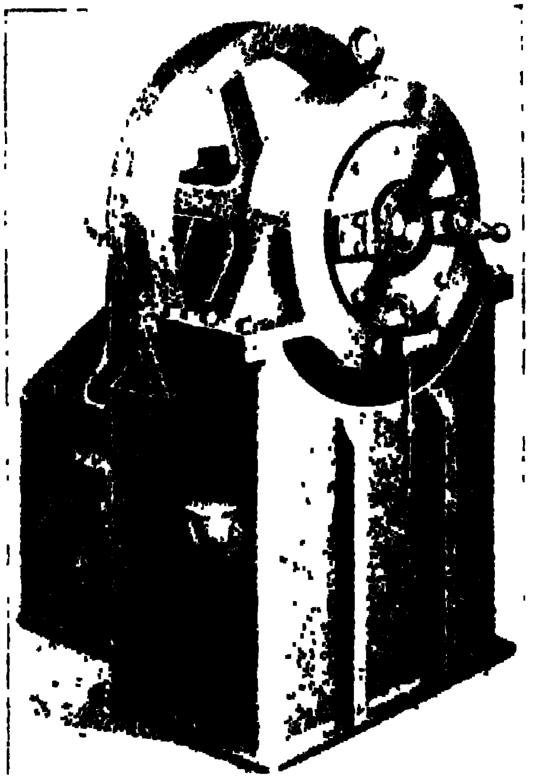
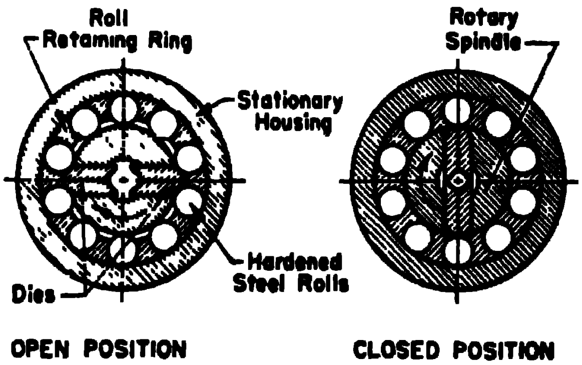


Fig. 18. Rotary Swaging Machine

Courtesy of The Torrington Swaging Machine Company, Torrington, Conn

The stock is fed into the circular opening in the head of the rotary swaging machine (Fig. 18). The operating speed of the machine and the number of blows the dies shall receive will depend upon the type of work (size and shape, composition of metal) and the amount of stock to be reduced in the swaging operations. If the machine is operated at a speed of 500 r.p.m. and there are 10 rolls, the number of blows struck would approximate 2,500 per minute.

The swaged portion of the work is always of round cross section, since the dies rotate around it. The original shape of the stock may be of any regular cross section—square, hexagonal, or octagonal. The kinds of work accomplished by swaging include: tapering of seamless or welded tubes, reducing and tapering diameters of rods, bars, and wire; swaging points; tapering shanks of tools; and reducing diameters of wire used in light bulbs, radio tubes, and various kinds of instruments.



OPEN POSITION CLOSED POSITION

Fig. 19. Sectional Views of Open and Closed Die Positions

Coining and sizing are cold-forming processes, which have been explained in detail in Chapter VII. These processes consist of applying compression on the metal in order to obtain close tolerances and impart a smooth finish to surfaces of parts made from iron, steel, and other metals, where a small amount of flow is involved. Parts which furnish good examples of coining and sizing have been shown in Chapter VII, Fig. 18.

REVIEW QUESTIONS

1. What is the principle involved in machine or upset forging?
2. Describe briefly the essential operation of upset forging.
3. What type of work is upset forging particularly suited to?
4. Describe briefly the operation of the Ajax air-clutch forging machine, as shown in Fig. 1 of this chapter
5. What is meant by the term "bar feed" as used in connection with upset-forging machines?
6. What is the function of the automatic ejector in upset-forging machines?
7. Describe briefly how upset-forging dies are designed
8. Name a number of products that are now being successfully formed by the machine or upset-forging method.
9. Describe briefly the sequence of operations carried out in upset forging the cluster gear, as shown in Fig 7 of this chapter.
10. In what way are the physical properties of an upset-forged product improved?
11. Describe briefly the fabrication of internal-recessed and deep-cavity forgings by the upset-forging method
12. Describe briefly the principal features of a forging machine that could fabricate the assortment of products shown in Fig. 10 of this chapter.
13. Describe briefly the operation of an automatic-feed production forging machine.
14. State the factors upon which the upset-forging temperature of metals depends.
15. When are temperatures below 1,500° F. recommended for preheating steel previous to upset forging?
16. State the range of upset-forging temperatures for steel, copper-base alloys, and aluminum alloys.
17. Describe briefly the operation of cold heading.
18. Describe briefly the sequence of operations in making a cold-headed part, as shown in Figs. 14, 15, and 16 of this chapter.
19. Describe the operation of cold swaging.
20. What methods are used for obtaining close tolerances and smooth surface finishes?

CHAPTER IX

Other Forging Methods

Forging Steel with the Aid of Rolls. A variety of shapes having straight or tapered reduced sections may be forged with the aid of rolls. The process consists of placing raw stock between two roll dies, which are of semicylindrical form, and which are grooved to impart a desired shape to the piece being forged. The amount of reduction and the complexity of the forging shape determine the required number of passes of the stock between the rolls. A roll-forging machine in operation is shown in Fig. 1.

The roll dies are carried on roll shafts, and rotate continuously toward the operator. Fig. 2 shows the principle of operation of a roll-forging machine. The view at *A* shows the rolls in open position, with the heated stock held between the rolls by the guides and adjustable gages. The view at *B* shows the rolls brought together, with the stock gripped in the grooves of the rolls. The rolling action forces the stock toward the operator. When the dies are again in an open position, the stock is placed in appropriate grooves of the rolls, and the operations are repeated as many times as may be necessary to obtain the correct shape.

If short reductions are sufficient for rolling very simple shapes, such as connecting-rod blanks, flat-backed segmental dies (Fig. 3) are used. These dies are economical to make, as most of the machining needed to cut their impressions can be done on both dies simultaneously. They weigh very little, and can be made of high-alloy steel. After machining, they can be heat treated to a high hardness, and the back surfaces can be ground to correct any warpage resulting from the heat treatment. These dies are bolted to the roll shafts between the housings so as to permit quick setting and easy changes.

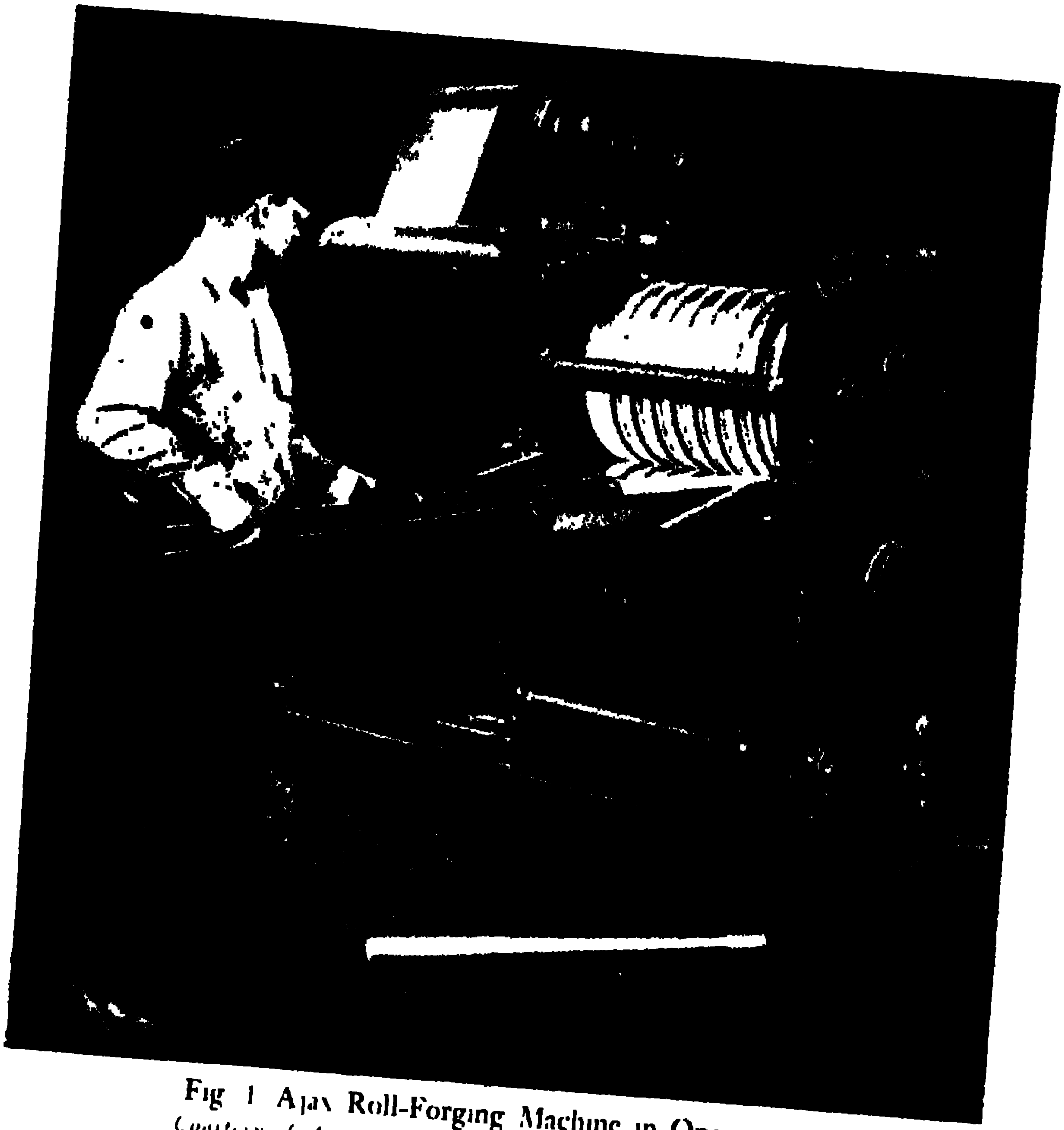


Fig. 1. Ajax Roll-Forging Machine in Operation

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

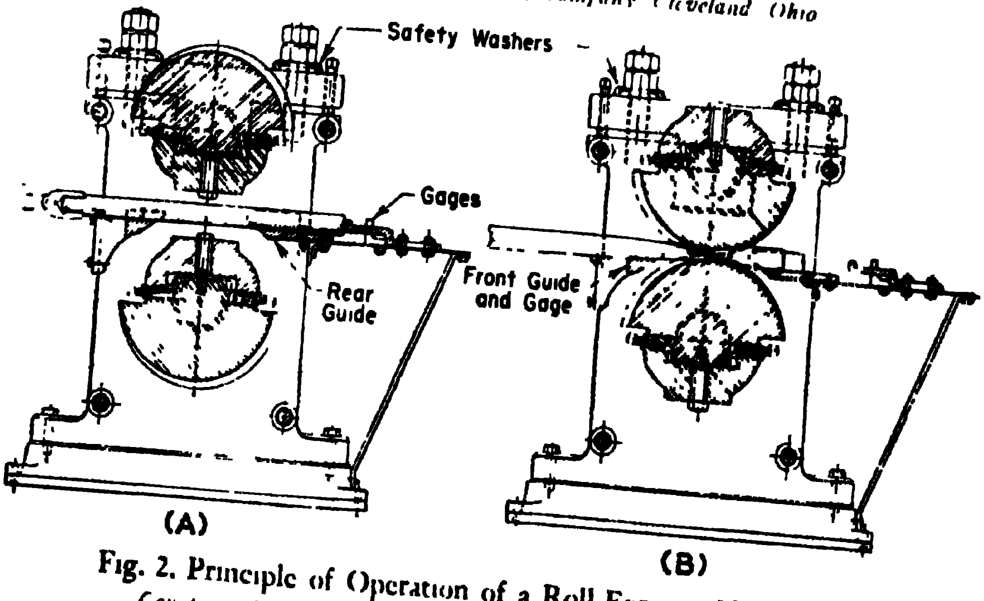


Fig. 2. Principle of Operation of a Roll-Forging Machine

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

For middle-length work, such as axle shafts, semicylindrical dies (Fig. 4) prove most economical. They, too, are bolted to the roll shafts between the housings, and can be conveniently changed. Most of the machining on the two halves can be performed simultaneously when mounted on an arbor. When the work is not too long, the dies can be made reversible—mouthed out at both ends of the impressions where most of the die wear occurs.

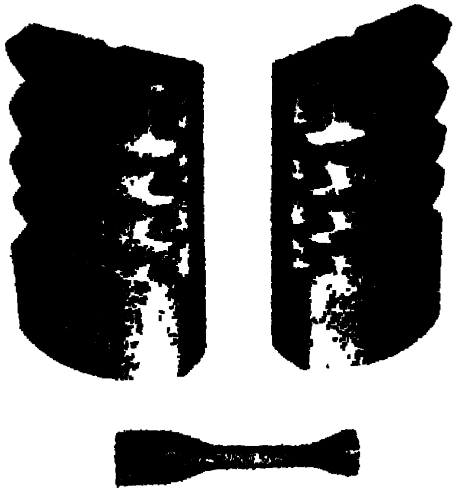


Fig. 3. Flat-Backed Segmental Dies

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

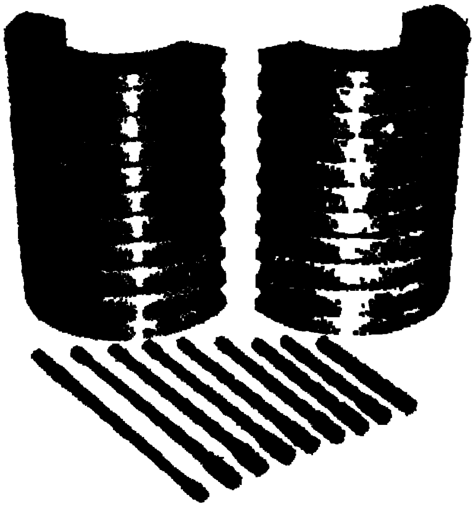


Fig. 4. Semicylindrical Dies

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

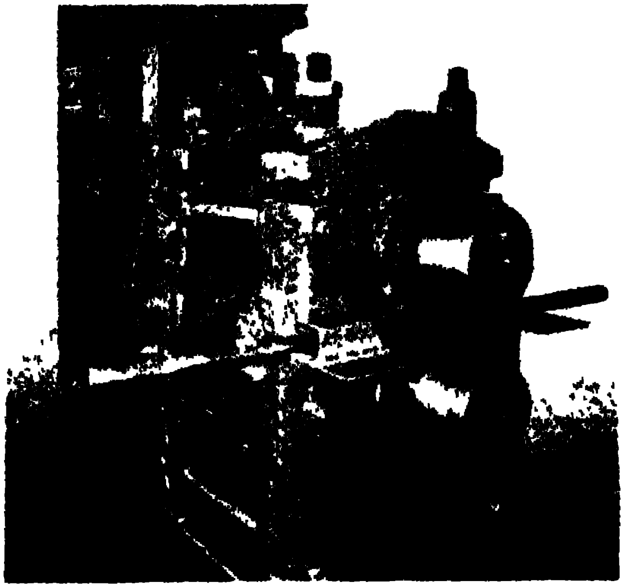


Fig. 5. Full Cylindrical Dies with Stock Inserted

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

For long work, full cylindrical dies are mounted on the overhanging right-hand ends of the roll shafts, as shown in Fig. 5. The dies can be made most economically as rings, with the cutaway portion sufficient only for feeding the blanks. Their width is limited by permissible overhang, so that the number of grooves must be limited. Overhang mounting of dies has the advantage of permitting easy changes.

A variety of forgings produced on a roll-forging machine are shown in Fig. 6.

Hydraulic Hot Piercing and Drawing. Hydraulic hot piercing of metals, particularly steel, consists of heating a solid metal blank of square cross section and placing it in a cylindrical die, which is located beneath and in line with the plunger of a hydraulically operated ram. The plunger, on its downward stroke, forces the heated blank to take the shape of the dies as the displaced plastic metal is moved upward and around in the space between the plunger and die, as shown in Fig. 7. Upon completion of the downward stroke, the ram moves upward, and the plunger is withdrawn from the cup-shaped blank. The formed piece is then ejected by a kicker pin.

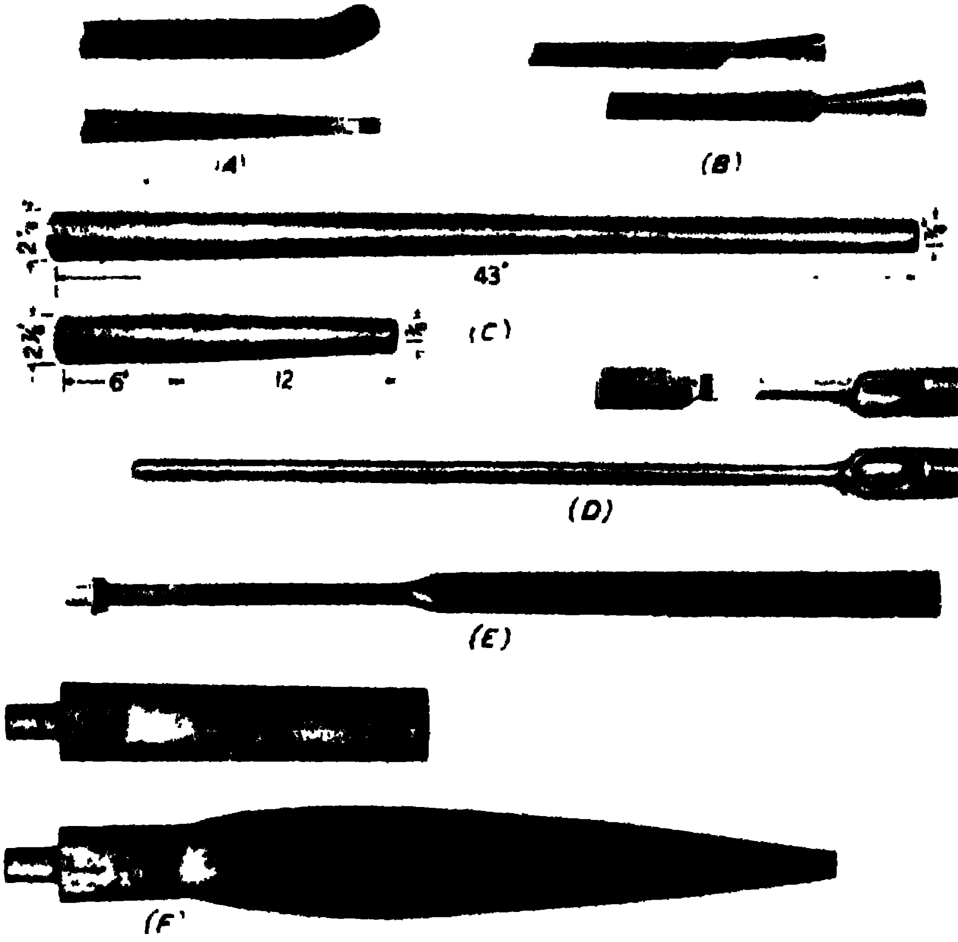


Fig 6 Forgings Made on a Roll-Forging Machine

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

The piercing process is usually followed by hot drawing, which consists of forcing the cup-shaped blank through a series of grooved rolls or annular dies built on a push bench. Thus, the cup-shaped piece is reduced in diameter, increased in length, formed into a tube.

Cylinders of various diameters, water, gas, and air bottles for example, are produced by the piercing process. Also, the production of tubes by the push-bench method utilizes the piercing process in the initial stages of operation.

Hot drawing, or "cupping," consists of heating a metal plate of definite thickness and circular shape, and placing it over a cylindrical die located beneath and in line with the plunger of a hydraulically operated ram. The plunger, on its downward stroke, forces the plastic plate through the die and forms a cup-shaped piece which drops downward upon withdrawal of the plunger, as shown in Fig. 8.

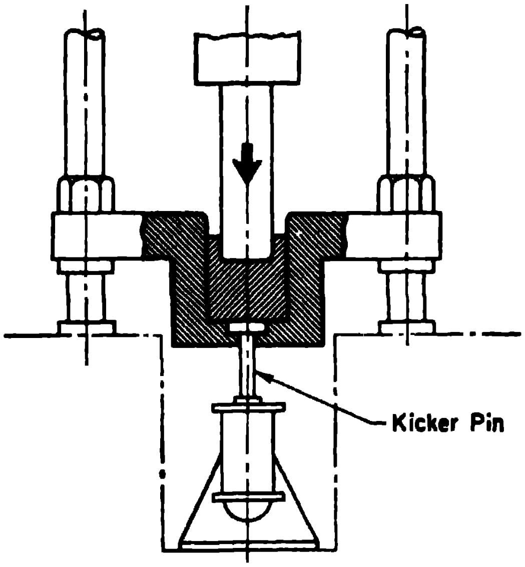


Fig. Hydraulic Piercing of Solid Blank

Courtesy of American Society for Metals

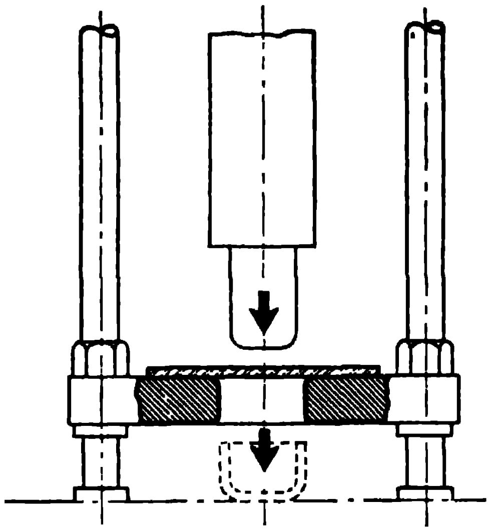


Fig 8 Hot-Drawing Operation

Courtesy of American Society for Metals

To prevent buckling in hot-drawing operations, clearance between the die opening and plunger is so amply provided that it exceeds the original thickness of the plate by a comfortable margin. Exactly what this margin should be is dictated by experience. Subsequent changes in the length, diameter, and wall thickness may be accomplished by reheating the cupped piece and forcing it through a series of drawing and reducing dies on a push bench.

Cylinders for containing oxygen and acetylene are produced by the hot-drawing process. Also, cylindrical containers requiring a closed end may be produced by this method. Closed-pressure vessels measuring as much as 5 feet in diameter and 45 feet in length may be formed by piercing and subsequently drawing heated ingots weighing 25 tons in one heat. Employment of these processes reduces production time and tool costs and minimizes the possibility of scaling. Necessary equipment for producing these large, seamless, hollow bodies consists mainly of a vertical hydraulic piercing press and a hydraulic push bench, as shown in Fig. 9.

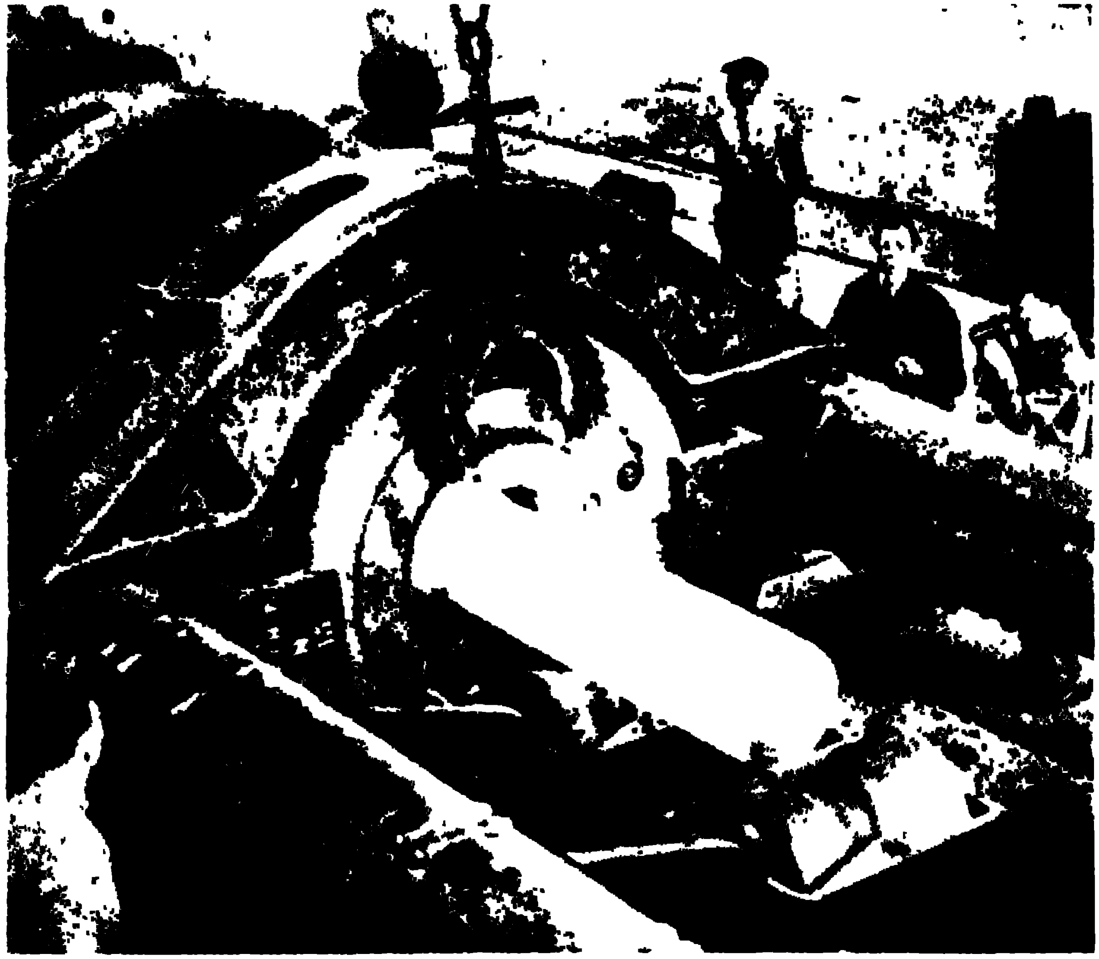


Fig. 9. A 1,500-Ton Hydraulic Push Bench

Courtesy of Hydropress, Incorporated, New York, N.Y.

Hot Extrusion of Metals. This is another process used in the plastic shaping of metals. It consists of heating a billet of suitable metal or alloy to its proper extruding temperature, and placing it in the cylinder of an extruding press, where pressure exerted by a moving piston or ram forces the plastic metal through a die of the required shape. The metals that best lend themselves to the hot-extrusion process are brought to temperatures near their melting points by the time they are ready to be forced through the die openings. These temperatures vary from 600° to 800° F. The practically liquid metals are squirted through the die and solidify upon exit. Fig. 10 shows an extruding machine in the operation of extruding rods, which may be seen emerging from the die onto a run-out table. These rods, upon cooling, are cut to the length desired.

Nonferrous metals and alloys, such as aluminum, copper, brass, magnesium, lead, etc., can be successfully extruded into various commercial shapes. Solid and tubular products of common cross section (round, square, or hexagonal) furnish examples of extruded pieces.

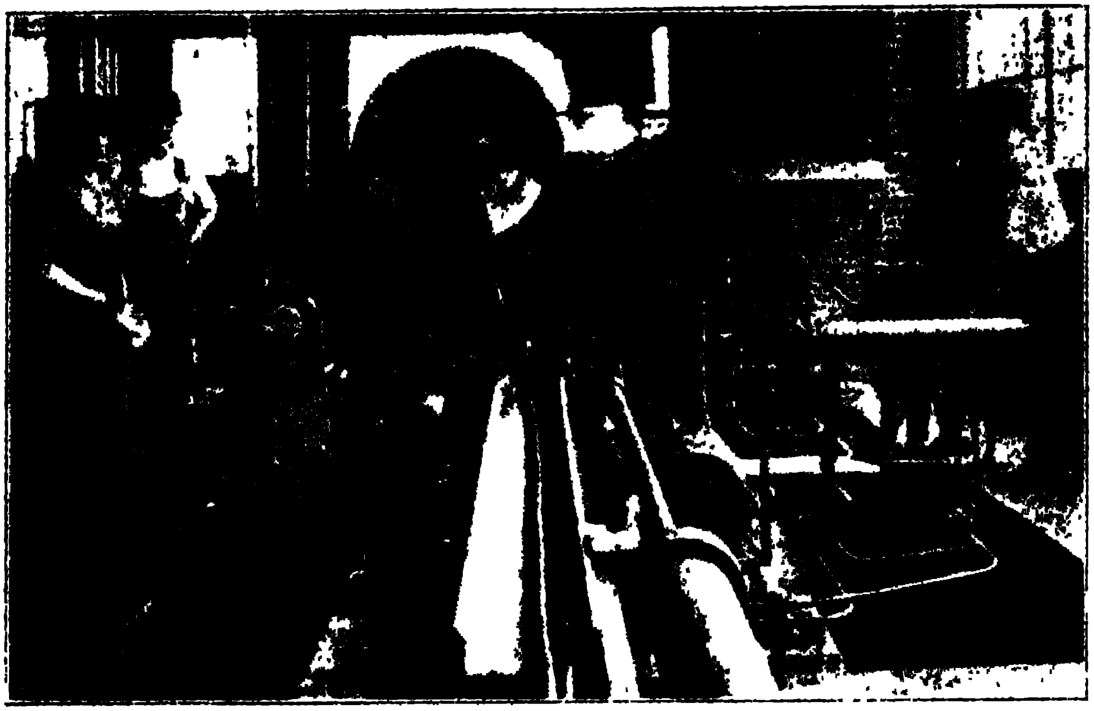


Fig. 10. A 1,000-Ton Extruding Machine Extruding Two Rods

Courtesy of Baldwin Southwark Corporation

Shapes that cannot be rolled may be successfully extruded. Extruded parts are correctly shaped within close tolerances. Their surfaces are clean and smooth, and their mechanical properties are high.

Fig. 11 shows a 4,250-ton extrusion press at one of the extrusion plants of the Reynolds Metals Company. Hot-extrusion presses are designed for normal operating pressures of from 80,000 to 100,000 p.s.i. Billets measuring as much as 14 inches in diameter are used.

Fig. 12 shows a schematic illustration of an extrusion press used for producing aluminum shapes. The hydraulically operated ram pushes hot aluminum through a die opening of desired cross section.

Fig. 13 shows the steel tools for producing aluminum shapes. The tools consist of a die, back-up block, die holder, die block, and tool container. Extrusion billet diameters range from 4 to 11 inches.

Extruded aluminum shapes offer many interesting possibilities as to sizes, weights, and types of shapes which can be produced. The maximum cross-sectional dimensions generally considered commercial are governed by a circumscribing circle approximately 12 inches in diameter. A limited number of 5,500-ton presses available in this country can handle sections circumscribed by a 17-inch circle. The circumscribing circle is the smallest circle which completely encloses a shape. Section thickness may vary from about 0.050 inch to several inches, depending on circumstances. The softer alloys can be ex-

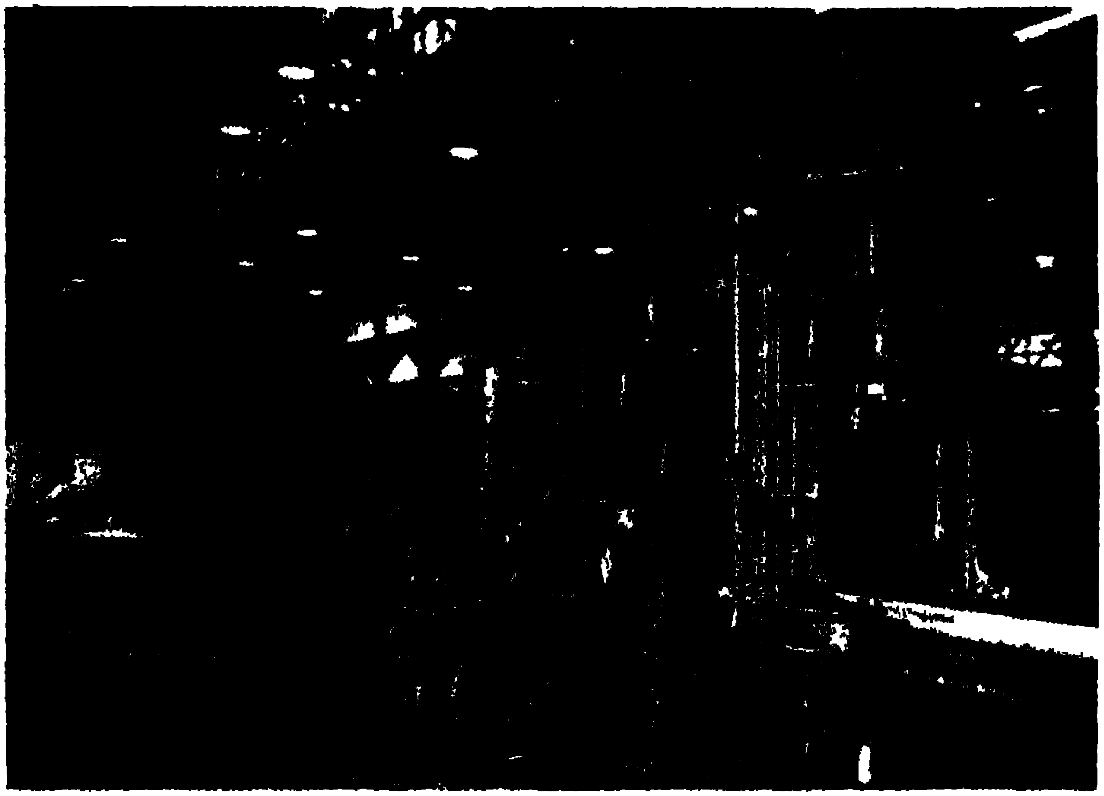


Fig. 11. A 4,250-Ton Extrusion Press

Courtesy of Reynolds Metals Company, Richmond, Va.

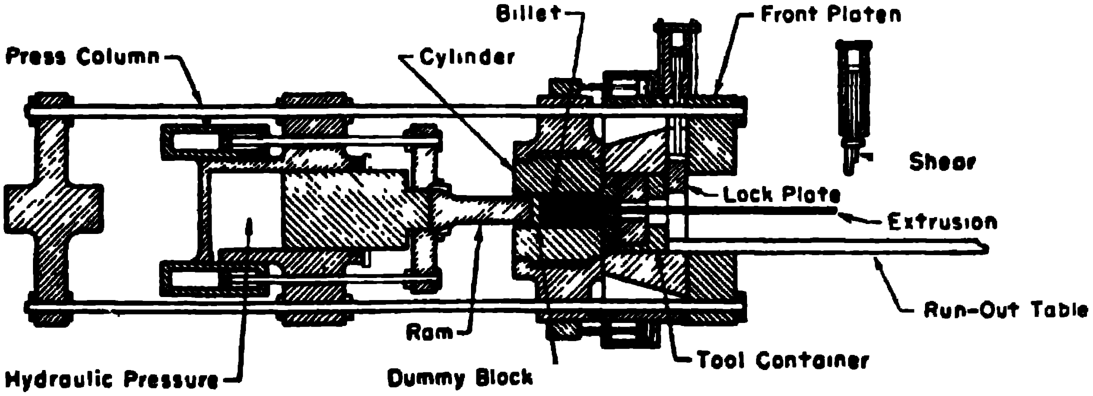


Fig. 12. Extrusion Press Used for Producing Aluminum Shapes

Courtesy of Reynolds Metals Company, Richmond, Va.

truded to thinner sections than medium- and high-strength alloys. Aluminum is extruded in rod, bar, tubing, and other standard structural shapes. Such special extrusions are classed according to degree of difficulty of production. Solid, semihollow, and hollow shapes increase, in that order, in difficulty of production.[1]

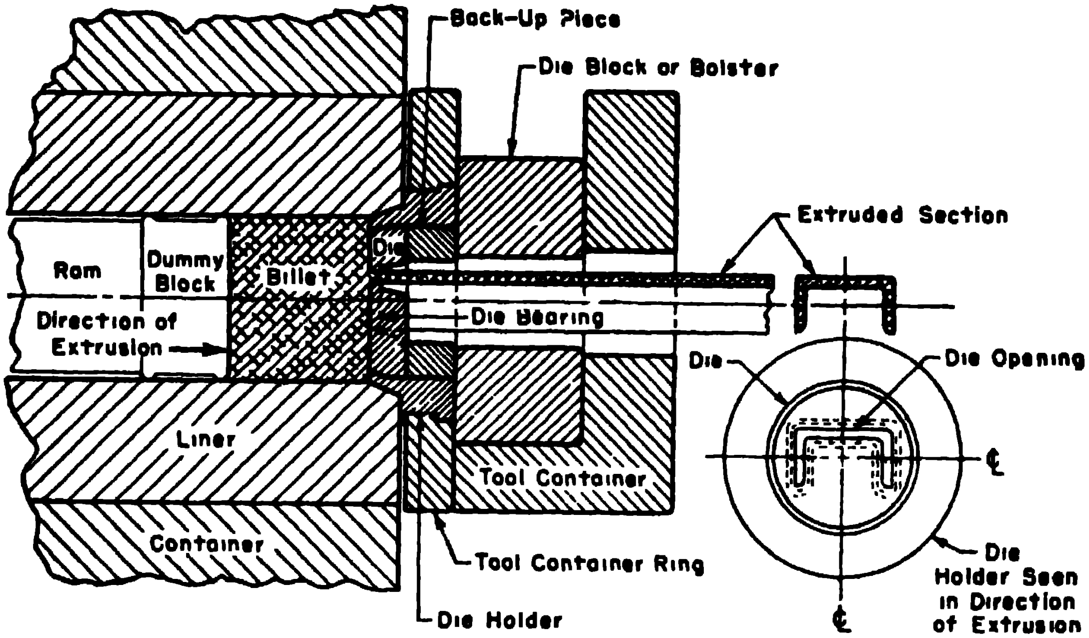


Fig. 13. Steel Tools for Producing Aluminum Shapes

Courtesy of Reynolds Metals Company, Richmond, Va

Fig. 14 shows the various types of extrusions.

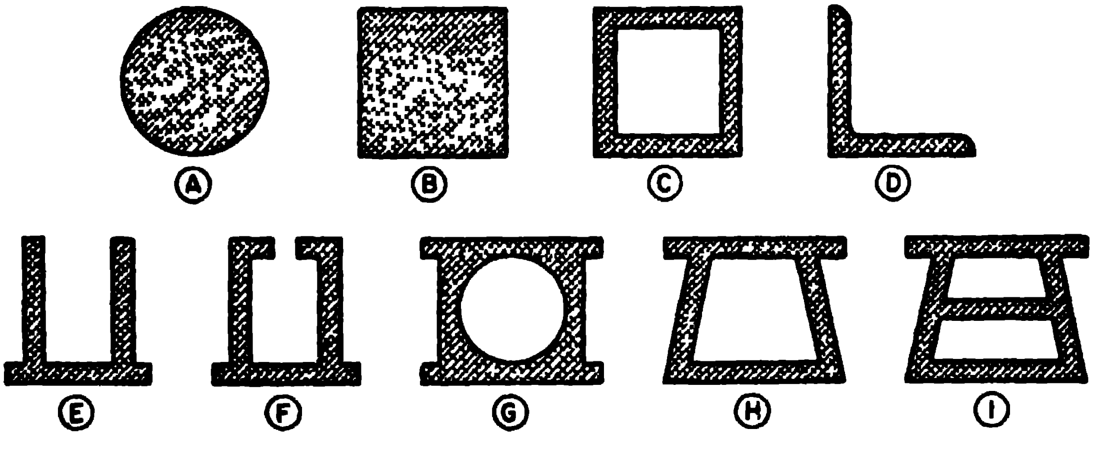


Fig 14. Types of Aluminum Extrusions

Courtesy of Reynolds Metals Company, Richmond, Va.

Cold Extrusion of Metals. This process is employed for the plastic shaping of metals, as is hot extrusion. The two processes are much the same, except that in cold extrusion, the metals worked possess the plasticity necessary for successful forming without the application of heat. Usually, these metals have a high degree of ductility. Cold extrusion is accomplished by any of several methods, among which the Hooker and impact processes are widely employed.

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[1] Discussion in this paragraph is adapted from *Designing with Aluminum Extrusions*, published by Reynolds Metals Company, Louisville, Kentucky, 1949

The Hooker, or *extrusion down*, method consists of forcing a thick-walled, cup-shaped blank through a die. The operation is carried out at high speeds on an ordinary crank press, the mass of metal in work being comparatively small. A crank press is actuated by one or more cranks. The crank-throw controls the stroke of the press. Examples of products extruded by this process are light, thin-walled, seamless tubes and small cartridge cases. Fig. 15 illustrates four operations in the making of a small brass cartridge case.

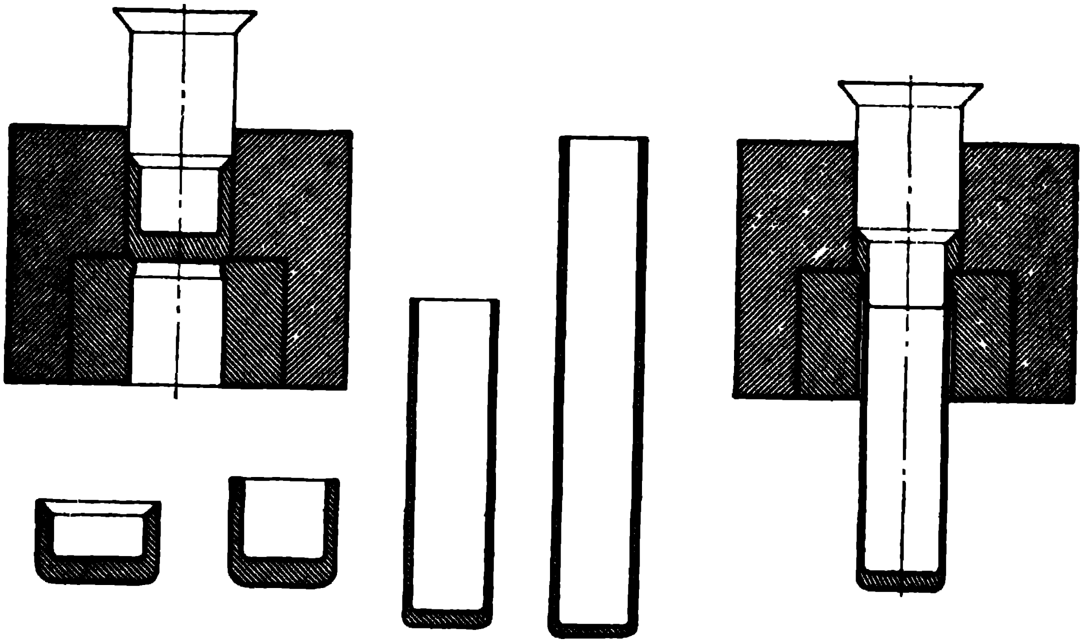

Fig 15. Sequence of Operations in the Production of a Small Brass Cartridge Case by the Hooker Method

Courtesy of American Society for Metals

The first two operations are conducted on a mechanical or hydraulic press before extrusion is begun, a flat blank of specified diameter and thickness being used. The blank may be either preheated or cold. In Fig. 15, one sectional view illustrates the position of the punch and the worked metal at the start of operations and the other sectional view illustrates their positions just before the finish. Pressure is exerted by the shoulder of the punch, the metal being forced to flow through the restricted annular space between the punch and the opening in the bottom of the die.

Small copper tubes and cartridge cases may also be extruded by the Hooker method merely by dropping a flat blank of specified diameter and thickness in a suitable die, and forcing it through the opening of the die with a punch, as shown in Fig. 16. Similar products of other soft metals may be extruded by this method.

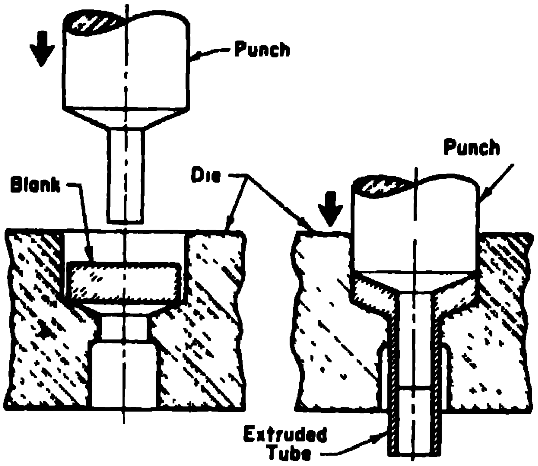

Fig. 16. Extrusion of Tubes and Cartridge Cases from Flat Blanks by the Hooker Method

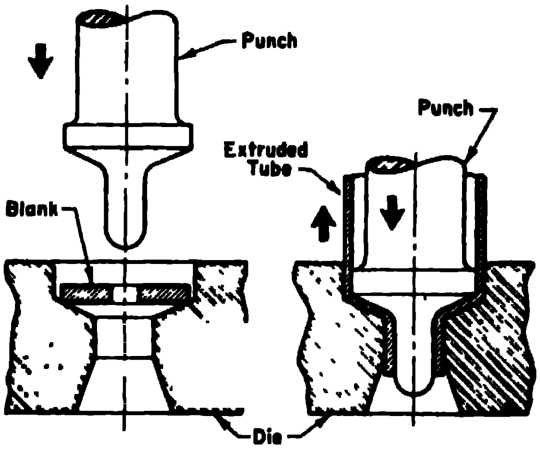

Fig. 17 Extrusion of Collapsible Tubes by the Cold-Impact Method

The impact, or *extrusion up*, method consists of dropping a flat blank of specified diameter and thickness in the die cavity, and then delivering a single powerful blow with the punch. This forces the thin metal to squirt up around the punch, as shown in Fig. 17.

Fig. 18 shows four steps in producing an impact-extruded part—a tube—from aluminum. A slug of high-purity aluminum is placed in the die cavity of the extrusion press. The descending punch strikes the slug with terrific force, causing the residue of metal to rise along the shank of the punch. The tube, thus formed, is ejected from the die position after the punch ascends.

Thin-walled tubes of ductile metals, such as tin and aluminum, are rapidly produced by this method. The outside of the tube takes the shape of the die, and the wall thickness is equal to the clearance between the punch and the die. The end of the tube may be of any form appropriate to the shape of the die cavity and also to that of the punch. When the punch is on its upward stroke, the tube sticks to it. To effect release, either a stripper device, described above, or compressed air is directed against the tube, thus stripping it from the punch. The operation is fully automatic throughout, and the pro-

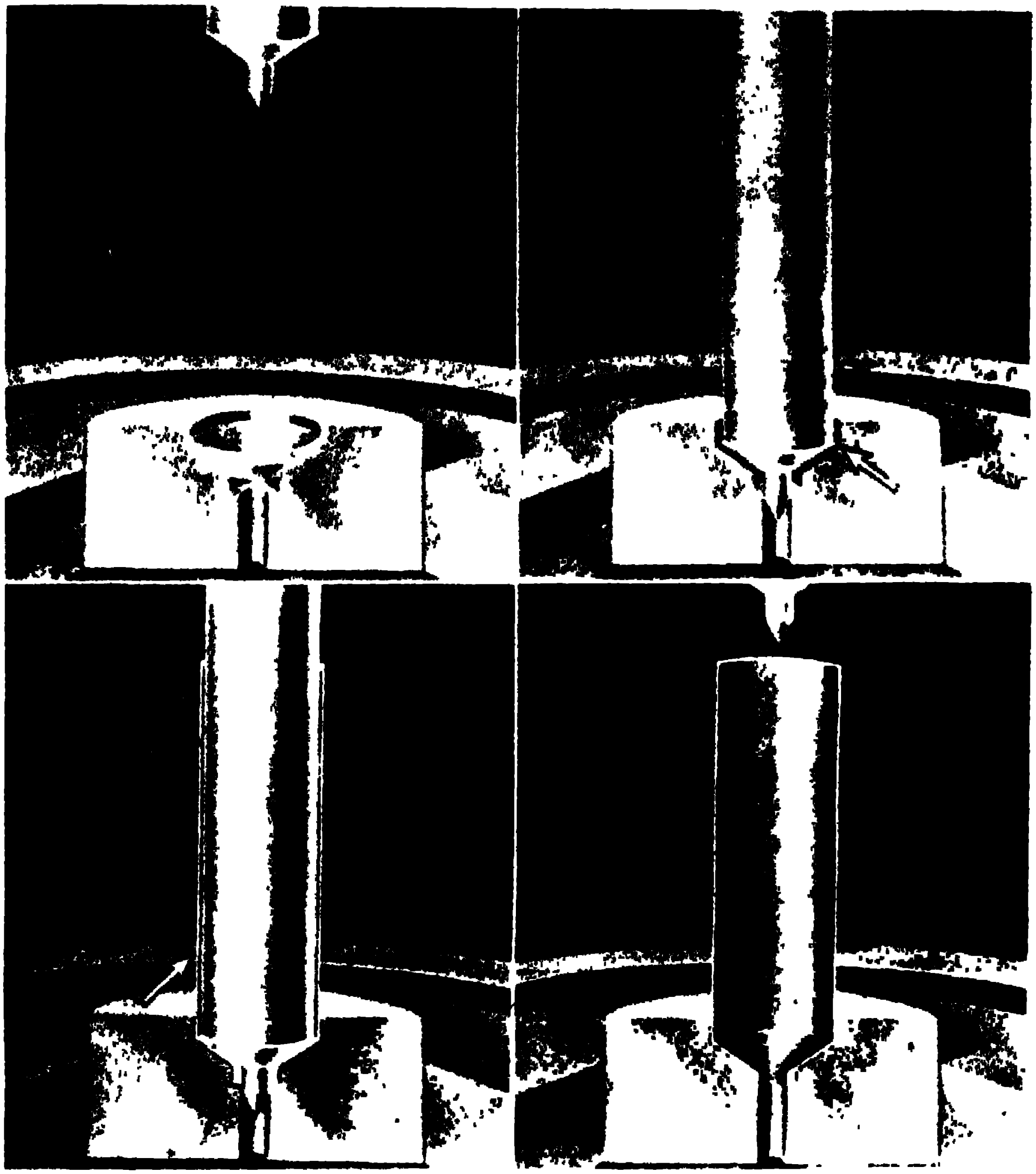

Fig. 18. Steps in Producing an Impact-Extruded Part—the Slug in Position (*upper left*), the Punch Striking the Slug (*upper right*), the Slug Metal Forced Up around the Punch (*lower left*), the Punch Withdrawn (*lower right*)

Courtesy of Aluminum Company of America, Pittsburgh, Pa

duction rate is as high as 50 tubes or more a minute. Pressures vary from 50 to 100 tons, depending upon the size of the tube. Thin-walled collapsible tubes for containing toothpaste, shaving creams, paints, etc., are produced economically by the impact-extrusion method.

Hot Spinning of Steel. This process consists of forming heated steel into hollow, cylindrical, and other continuous shapes, such as boiler heads, tank bottoms, etc. Special spinning and flanging machines have been developed capable of spinning heads in diameters up to 20 feet, which are used in extra-large processing equipment. Accurate control of the metal during spinning is maintained. Thus, distortion of grain structure is eliminated and residual stresses are reduced. Fig. 19 shows a hot spinning operation by which a large steel head for a pressure boiler is formed on one of the large spinning machines.

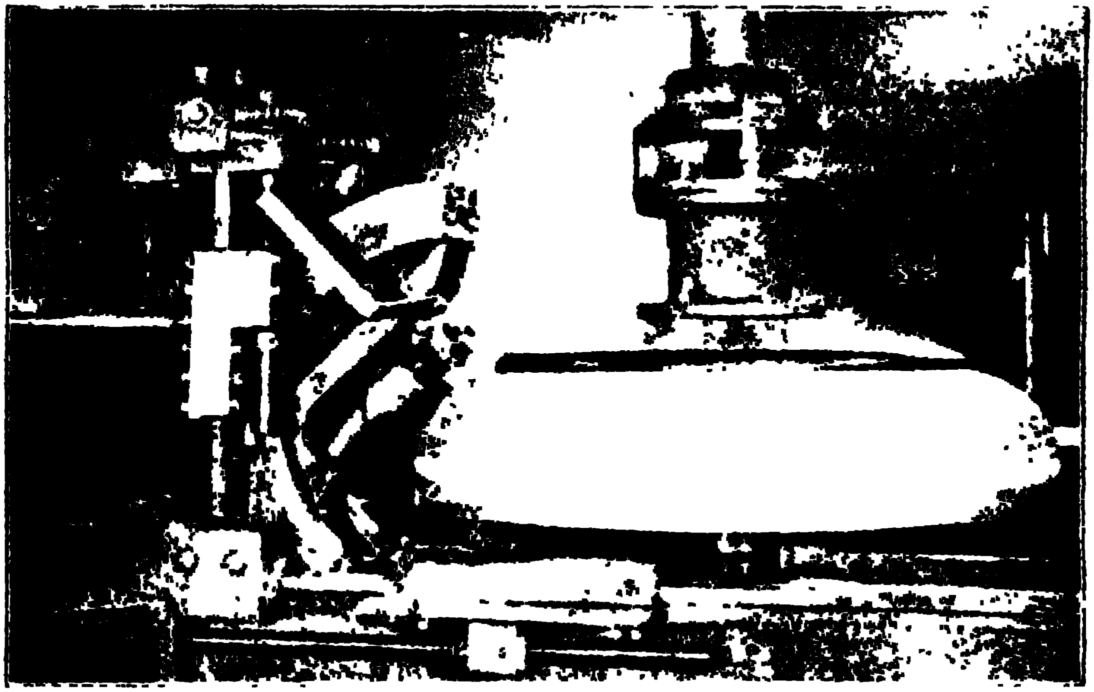

Fig 19. Forming a Head for a Pressure Boiler on a Large Spinning Machine while the Metal Is White Hot

Courtesy of Lukens Steel Company Coatesville, Pa

Close adjustment of linear speed for more even shaping pressures is assured by the use of mercury rectifiers for the motor which drives the spindle at continuous speeds. More precise work, particularly in heavier gages, is made possible by the introduction of increased clamping capacity, which eliminates slippage. The quadrant housing seen at the left in Fig. 19 permits shaping to closer tolerances on a more uniform contour. It also permits more accurate control of reduction in thickness of the metal during spinning, which results in a more uniform product. The surface of the shaped product is also substantially improved by the use of backing rolls on the quadrant roller to eliminate chatter. The heads produced on special spinning machines may vary in size, gage, style and material. Included among the materials that best lend themselves to spinning are the clad steels and nonferrous metals. A *clad steel plate* is a composite plate—one made up of a backing layer of carbon or low-alloy steel that has, on one or both of its surfaces, a uniform and inseparably bonded cladding of some corrosion-resistant metal.[2]

Hot Forming of Seamless Tubing. This process is used extensively in the manufacture of seamless tubing. Cylindrical billets of steel are heated and passed through a specially designed piercing machine. The principal parts of the machine are two conically shaped rolls (the axes of which are in different planes) and a pointed mandrel over which the pierced steel is forced. The direction of rotation of the rolls and mandrel is the same. The sequence of operations carried out in producing seamless tubing is shown diagrammatically in Fig. 20.

The steel billet, which is a solid round bar, is center-punched at one end and heated to a plastic temperature. It is then placed in the piercing machine and forced into contact with the piercing rolls In the next step, the rolls grasp the billet and pull it forward. The rotation of the rolls and the billet is very rapid, while the forward feed of the billet is slow. Because of violent action of the rolls, the worked metal is ruptured at the center, owing to induced stresses of high severity. As the billet is drawn forward over the pointed mandrel, the hole becomes larger and, at the same time, elongated. Thus, a rough tube is formed. This operation is continued until the billet has passed through the piercing rolls for its full length. Upon completion of the operation, the mandrel is forced out of the roughly formed tube and plunged into water for cooling. Another cold mandrel is placed in the machine, and the operation is repeated on the next billet.

The operation which follows consists of forcing the roughly formed tube over another mandrel, and passing both tube and mandrel between the grooved rolls of a rolling mill, as shown in the third view from the left of Fig. 20. This operation elongates the tube the required amount and reduces the wall thickness.

The outside diameter of the tube is only approximate, however. The tube is still in a rough state. Therefore, another operation, called *reeling*, is performed between reelers and over a mandrel, as shown in Fig. 20. Finally, a sizing operation is performed between sizing rolls without use of a mandrel. The final operations of reeling and sizing are often conducted on cooled tubes in order to improve their finish and size. This procedure is called *cold drawing*.

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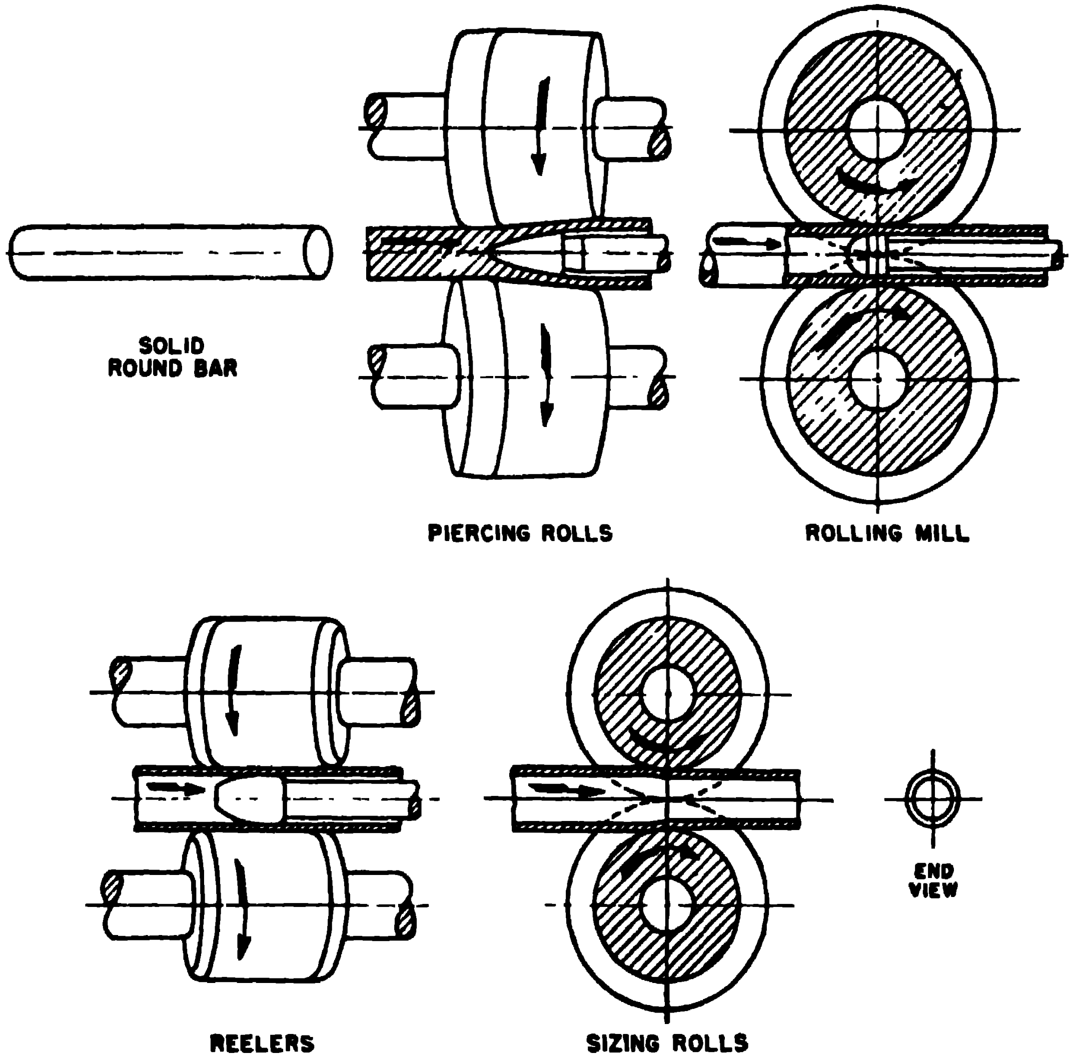
[2] Discussion of clad steel in this paragraph is based upon information contained in *Fabrication of Lukens Clad Steels*, published by Lukens Steel Company of Coatesville, Pennsylvania, 1948. Adapted with permission.



SEAMLESS PROCESS

Fig. 20. Sequence of Operations in the Production of Seamless Tubing

Courtesy of National Tube Company, Pittsburgh, Pa.

Welded Steel Tubing. Pipes and tubes may be produced either by seamless processes or by welding. Welding processes employed in the fabrication of tubes may be of four varieties as follows:

1. *Butt welding*, which is recommended for diameters ranging from $\frac{1}{8}$ inch to 3 inches.
2. *Lapp welding*, for diameters from 2 inches to 22 inches.
3. *Hammer welding*, for diameters from 20 inches to 96 inches.
4. *Fusion welding*, for diameters from 6 inches up.

Tube forming by welding consists of feeding cold flat stock continuously from coils through forming rolls, which gradually shape the metal to a circular form, and then welding the butted edges together. The flat stock is trimmed in the mill to the width necessary for forming the required diameter of the tube. It is then rolled into coils before the tube-forming and welding operations are begun.

Fig. 21 shows the method of gradually forming flat steel into a tubular shape without undue strain on the material. This shaping of the metal by easy stages insures that it will be free of any appreciable stress that would be present if the forming were drastic. In the first operation, the stock passes through a pair of driving rolls. It then goes through a series of forming rolls, which gradually curve the flat stock to the required tubular section. These forming operations are performed cold. After they have been completed, the butted tube is welded. Various welding operations are employed to seam the longitudinal edges of the formed stock. The electric-resistance process uses a welding unit that employs a current of high amperage which passes through a pair of copper-alloy, disk-shaped electrodes contacting both edges of the formed tube, which is shown in Fig. 22.

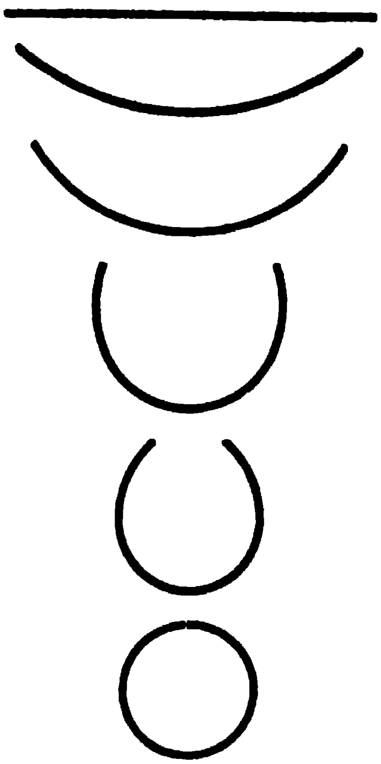


Fig. 21. Method of Gradually Forming Flat Steel into Tubular Shape without Undue Strain on the Material

Courtesy of Formed Steel Tube Institute

The welding unit is adjustable vertically, and is designed for convenient regulation of the current fed to the electrodes as well as for speed of operation. While the formed stock is inserted beneath the electrodes, the current travels from one electrode to the other across the joint of the stock. The resistance of the metal-edged surfaces creates a heat that is adequate for welding. The heated edges are forced together by side pressure rolls *B* and bottom pressure roll *A*, as shown in Fig. 22. A welded joint is formed by this action.

The extreme edges of the butted joint are heated to a temperature considerably above the plastic temperature of the metal. When the pressure rolls are applied, this overheated material is squeezed outward, leaving the unexposed plastic material to make a welded joint.

This method of welding the tube requires that only the edges shall be in a plastic state. Therefore, the heat is rapidly dissipated.

The excess metal (flash) remaining from the welding operation is removed by suitable cleaning and finishing operations. Following this, the tubing is ready for the cutoff machine. This machine moves with the tubing, and cuts it off to desired lengths. Thus, the operations of tube forming and welding are maintained continuously by such arrangement. Other methods of joining tubes by welding are as previously described.

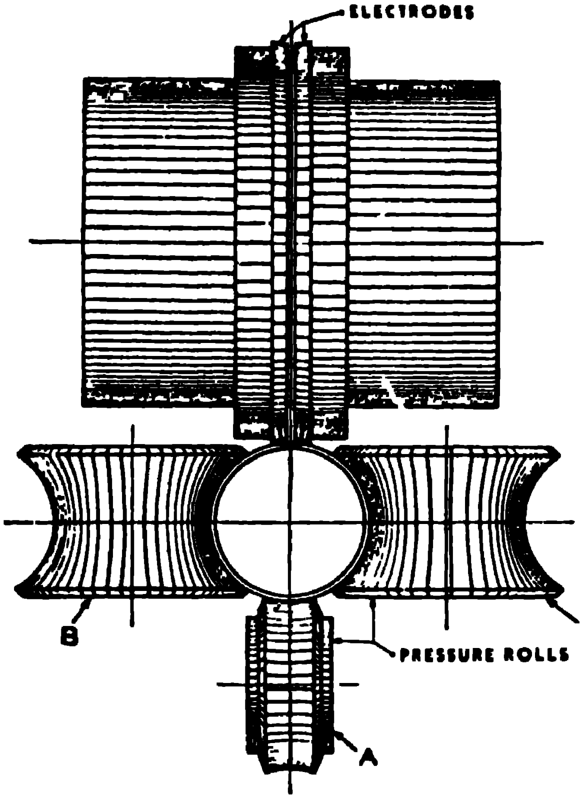


Fig. 22. Electric Resistance Welding Method

Courtesy of Formed Steel Tube Institute

Rapid production of butt-welded pipe in large quantities may be accomplished by a more economical method than the one described above. Although this cheaper method of making butt-welded pipe results in a product of less dimensional accuracy, it is quite satisfactory. Strict accuracy is not demanded for commercial work. This method consists of crimping one end of a flat plate, called the ***skelp***, as it comes from the steel-rolling mill. The skelp is charged into a furnace, where it is heated to its welding temperature, which is approximately 2500° F. The hot skelp is drawn out of the furnace by grasping its crimped end with tongs, over the handles of which a *welding bell* is slipped. This process is shown in Fig. 23.

One of the tong handles used in drawing the hot skelp out of the furnace is so shaped that it can be engaged by a continuous draw-chain which pulls the skelp through the welding bell. The edges of the skelp are folded together and welded into a pipe, as shown in the center of Fig. 23. The welded pipe is now transferred to the sizing rolls, as shown at the bottom of the figure. These rolls are shaped to fit the outside of the pipe and give it a fairly correct outside diameter.

This operation is followed by a final sizing, which is accomplished by a series of cross-rolls. At this stage, the outside diameter of the pipe is finally corrected to the dimension specified, and its surface appearance is improved, owing to the fact that the scale was removed in the final sizing operation.

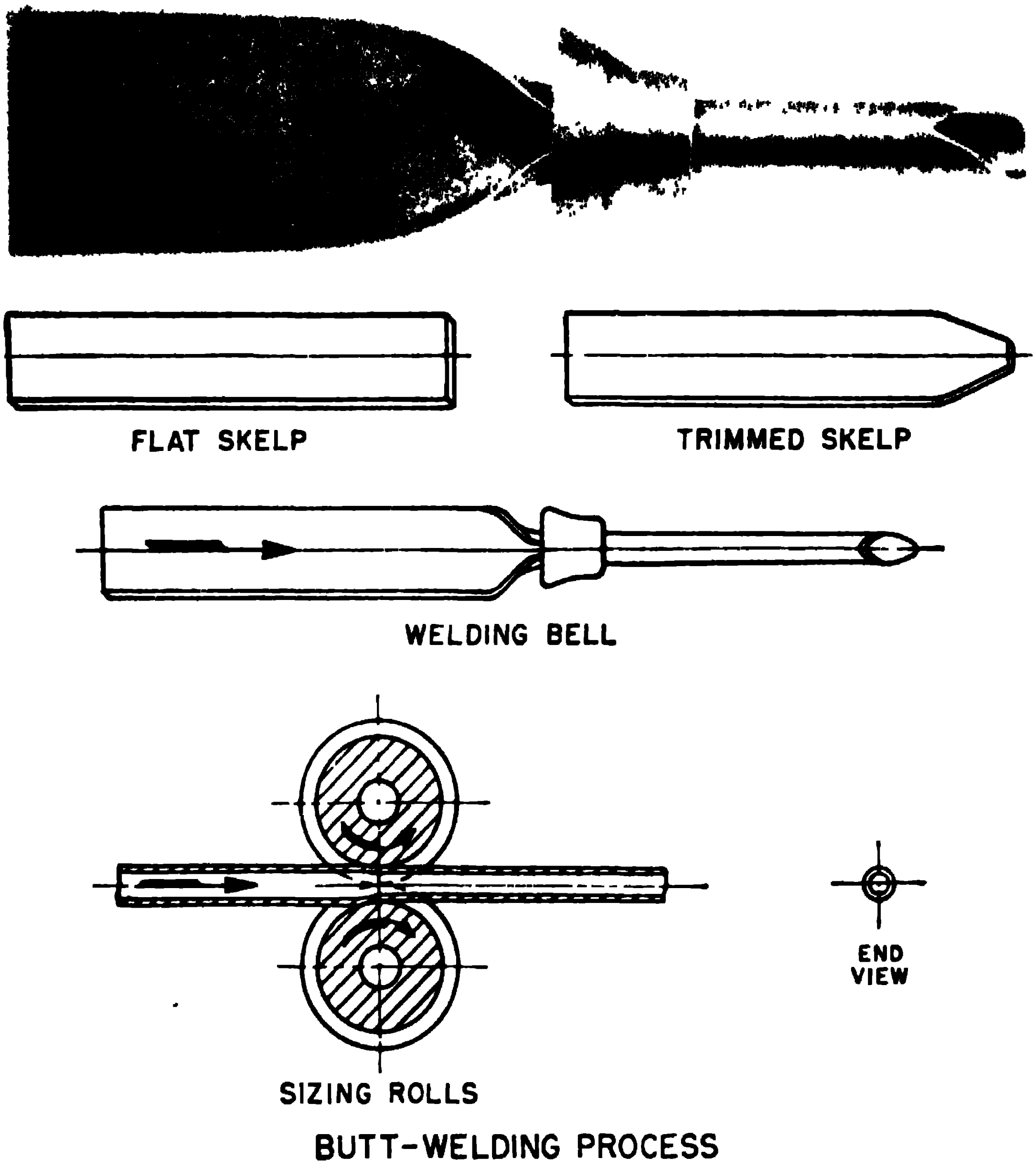


Fig. 23. Welding Bell Used in Butt Welding

Courtesy of National Tube Company, Pittsburgh, Pa.

Following the final sizing, the pipe is moved to the straightening rolls. After straightening, it is washed in water, and the ends of the pipe are trimmed and threaded. This method is suitable for rapid production. Three hundred pipes of 20-foot length each may be pro-

duced per hour. In a similar manner, pipes may be produced by lapp welding instead of butt welding.

Hot Swaging of Metals. These operations may be carried out with the aid of hand tools or dies attached to steam or other types of power hammers used for forming purposes, such as: forming a smaller diameter of the open end of cylinders used as containers for compressed gas, forging to shape where smooth and accurate sections are wanted; and forging even, round tapers. Fig. 24 shows swaging operations being performed on a gas cylinder.

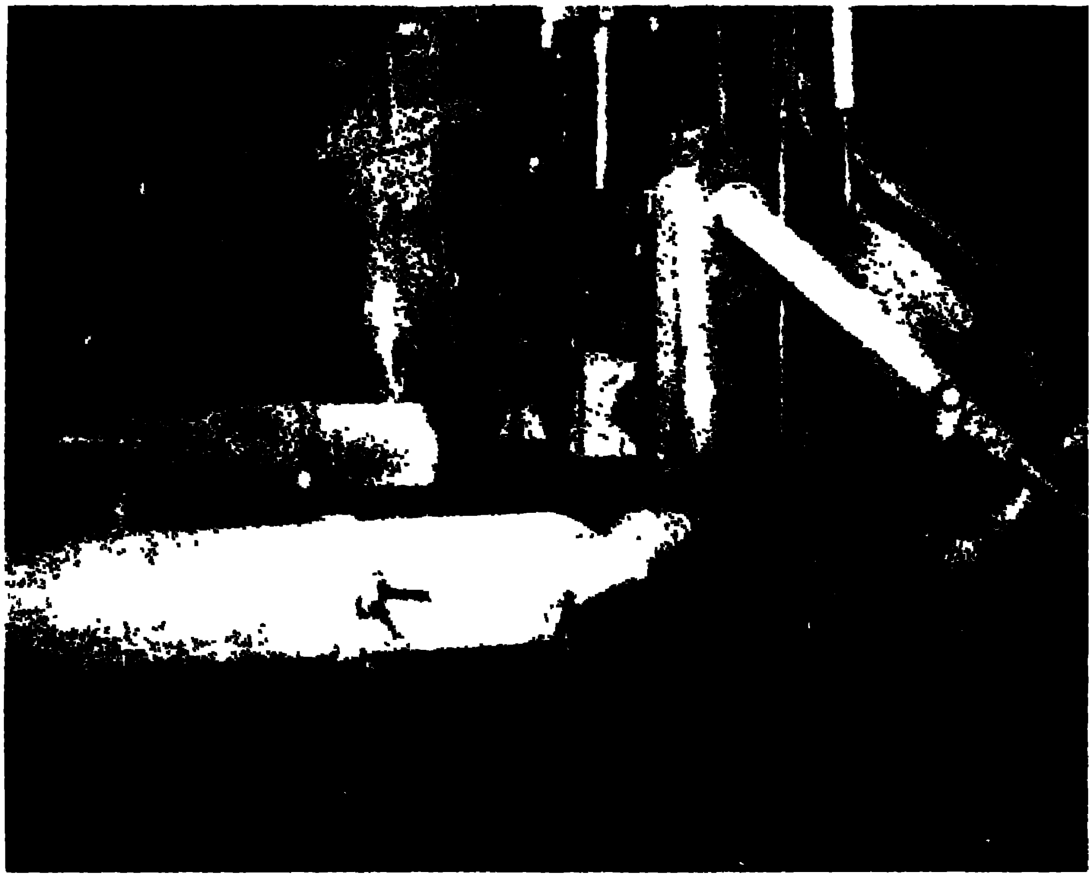


Fig. 24. Swaging Operations Used in Shaping Open End of Gas Cylinders

Courtesy of National Tube Company, Pittsburgh, Pa

These operations consist of heating the open end of the cylinder to a forging temperature, and then hammering it between dies. This method is especially recommended for cylinders whose diameters are greater than 6 inches. For smaller diameters, ordinary seamless tubing is selected. One end of the tube is heated, and then is rapidly rotated in a spinning machine. A blunt high-speed-steel tool forces the heated plastic material to flow and close the end of the tube.

The Bulldozer as a Metal-Forming Machine. The bulldozer is a metal-forming machine designed for shaping heavy-gage metals. It is used to advantage for forming deep bends, which an ordinary forming press would not do as well. Fig. 25 shows a bulldozer designed for heavy work. This machine consists of a welded steel bed that is heavily ribbed for strength and rigidity. Critical working surfaces are lined with hardened toil-blocks to resist wear. A cross-head slides on the bed toward the toil blocks during the working stroke, and then returns. Simple dies are used, which are brought into close contact by the controlled motion of the sliding head. The head is usually motor-driven by direct gearing, and is operated by a friction clutch.

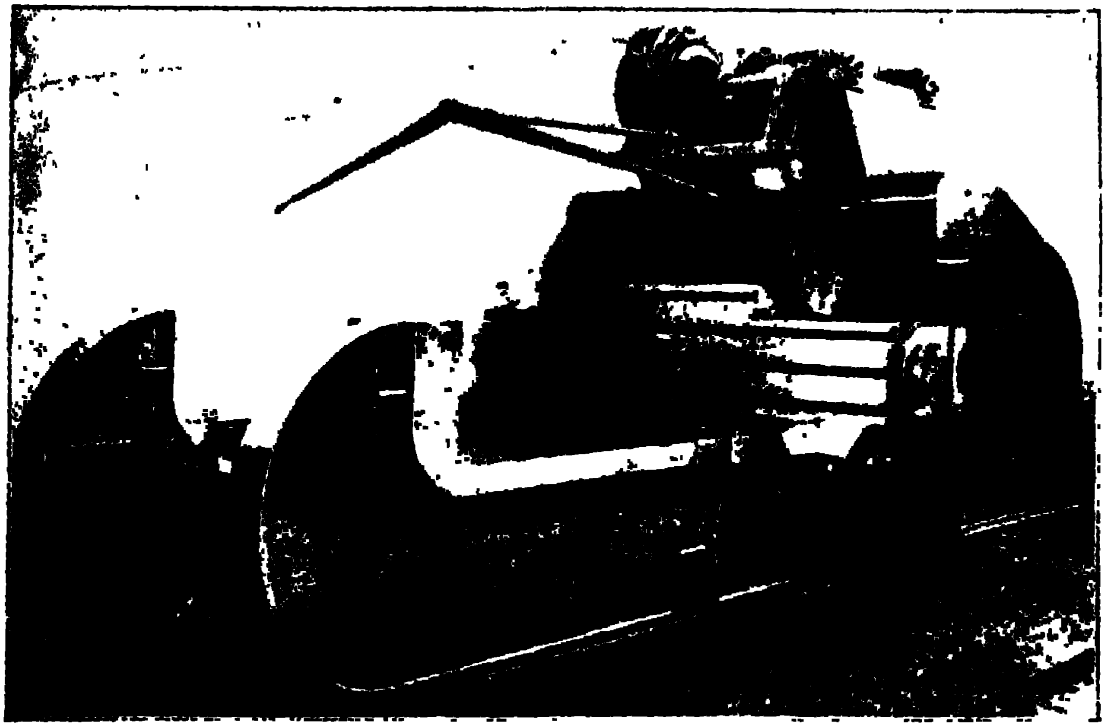


Fig. 25. Slow-Speed Bulldozer—a View Showing Heavy Ribs That Extend beneath Floor Level To Provide Strength and Rigidity

Courtesy of Ajax Manufacturing Company, Cleveland, Ohio

The operation of the bulldozer consists of placing the stock to be formed between the dies, after which the clutch is thrown in. The massive head moves forward, bending the stock upon contacting it. The metal is usually heated, before forming, to prevent its rupture at the point of bending. Bends in thin stock and shallow bends in heavier stock may be formed without heating the metal. The bulldozer is also a useful machine for other metal-working purposes, such as shearing, punching, straightening bent metal parts, and other utility operations.

REVIEW QUESTIONS

1. Describe the principle of operation of a roll-forging machine.
2. When are flat-backed segmental dies used in the forge rolling of metal?
3. When are semicylindrical dies employed in the forge rolling of metal? When are full cylindrical dies employed in the forge rolling of metal?
4. Describe the operation of hydraulic hot-piercing of metals.
5. Describe the operation of hot-drawing or cupping of metals.
6. Name several practical applications of the hot-drawing process.
7. Describe briefly the operation of hot extrusion of metals.
8. Name the metals and their alloys which can be successfully extruded into various commercial shapes.
9. Describe briefly the important features of the extrusion press.
10. What is the limiting capacity of extrusion presses at the present time?
11. How large are the sections which may be extruded by these presses?
12. Describe the principle of cold extrusion of metals.
13. Describe briefly the Hooker method of extrusion.
14. Describe briefly the impact or extrusion-up method.
15. What is meant by hot-spinning metals?
16. Describe the spinning operation of forming a steel head for a pressure boiler.
17. Describe briefly the operation of hot-forming a seamless tube.
18. What are the final operations in producing finished steel tubes?
19. Describe briefly the operation of producing steel tubes by welding.
20. Describe the operation of hot-swaging metals.
21. How is the bulldozer employed as a metal-forming machine?

CHAPTER X

Cleaning and Finishing Forgings

Removal of Oxide Scale. After forgings are formed by any of the previously described methods, they are, in most cases, subjected to some kind of cleaning, either before or after the prescribed heat treatment. Steel forgings, after being formed, are coated on the surface with a thin layer of iron oxide or scale, which is caused by contact of the heated steel with air. The amount of scale that is formed depends upon the forging temperature to which the steel is heated and the length of time required to complete the operational steps before the forging is fully developed. The scale may be removed by several methods. One simple way is to employ steam or compressed air to blow the scale away while the forging is being shaped. A pipe is attached to the lower die through which a continuous blast of air is delivered to blow the scale from the forgings as rapidly as it is formed. A flexible hose to deliver the air is more suitable for use with large forgings, because their big areas require shifting of the duct from one position of the die to another. When the heated stock is being hammered or squeezed between the dies, the formed scale begins to crack and separate from the forged material, and fall into the die. It is good practice to eliminate this scale immediately from the product, especially from the lower die, before subsequent operations are performed. Upon completion of the last step, the scale is again blown out from the dies, thus making them ready for the following cycle.

When forgings are finally shaped in the last die-impression, they frequently have a tendency to stick to the dies. A suitable oil is recommended for spraying on the dies in order to relieve them from the adhering workpiece. A minimum amount of oil is used for this purpose, because the heated dies would be in danger of deterioration if they came in contact with a large amount of fluids. Release of an excess of fluids on heated steel reduces its hardness and thus accelerates wear.

Scale removal from forgings is important from the point of view of machining these forgings. Cutting tools used in machining would have a shorter life if the scale were permitted to remain 'on the forgings. Furthermore, precise machining of forgings to close tolerances would be very difficult if these forgings were to retain the scale on their surfaces. Some forgings are used in critical service, at high speeds and under heavy loads. The scale formed on their unmachined surfaces will have a tendency to penetrate into the oil used to lubricate bearings and other vital elements in machines, engines, and mechanisms containing such forgings. Thus, to prevent such occurrence, thorough scale disposal is carried out in the forge shop before the forgings are permitted to be transferred to other branches of metal processing. Those forgings which require painting or other surface coating must be descaled, or else the retained scale will prevent successful painting and coating. In isolated cases, the belief is that the scale should be retained. Pipe fittings furnish an example of a case where such practice is beneficial. The unremoved scale prevents deterioration of parts constantly exposed to the influence of corrosion.

Cleaning of Forgings by Pickling, Tumbling, and Blast Cleaning. Pickling is a cleaning process which consists of immersing the forgings in a tank filled with an acid solution. The action of the solution is to loosen the scale and remove it from the surfaces of the forging after the latter remains in the pickling tank a predetermined time. The acid pickling solution is just strong enough to affect only the scale on the forging. A suitable inhibitor agent is frequently placed in the pickling tank in order to protect the clean metal proper from the action of the acid solution as it loosens the scale on the surface of the metal.

The acid pickling solution for descaling steel forgings consists of a 12- to 15-per cent concentrate of sulphuric acid in water. The acid solution is heated to the recommended temperature, which varies with the type of work being descaled, and is maintained at that level through means provided to keep the temperature constant. Periodic checks are arranged for maintaining the required solution strength. Suitable acid solutions are being used in industry and are recommended for successful descaling of nonferrous forgings, such as copper, brass, bronze, aluminum, and monel.

Tumbling is another process employed for the removal of scale and general cleaning of forgings. The equipment used in tumbling is fairly simple. It consists of a tumbling barrel, which holds the work to be cleaned, and some sort of loose abrasive, such as coarse sand or small particles of metal. A simple mechanism is arranged to rotate the tilted barrel at slow speeds. The forgings are dumped into the barrel and are cleaned by being tumbled through the abrasive material. The forgings and abrasives roll over themselves, and thus the scale is loosened from the surfaces of the forgings. Satisfactory results are obtained after ten to forty minutes of tumbling, depending upon the type of size of forgings. The forgings, besides being cleaned through the action of the abrasive particles rolled over them, obtain a certain amount of beneficial effect from the peening or hammering action of these abrasives. It is believed that some of the stresses in forgings resulting from the previous working operations are somewhat relieved by the peening action of the loose particles of coarse sand and metal used in the tumbling process. Care must be exercised when forgings having sharp edges and sharply defined sections are tumbled. The work, in some instances, can be damaged by the action of the abrasives. Other methods of cleaning such forgings may be more suitable.

Sandblasting and metallic-shot blasting of forgings are other cleaning methods employed successfully in modern cleaning operations. Various methods and machines are used for blast cleaning of forgings. One method consists of directing a jet of sand, grit, or metallic shot (usually white cast iron) against the forgings. The blasting power is supplied by compressed air or centrifugal force through suitably designed apparatus. The abrasive material jets from the nozzle with sufficient force to clean the forgings of scale. Blast cleaning is used mostly in descaling forgings, since its effect is more pronounced and the operation is rapid, especially in volume production of small and medium-size forgings. Besides removing scale, the blast-cleaning process also imparts a smooth surface finish to the forging.

Modern Equipment for Rapid and Effective Cleaning of Forgings. Fig. 1 shows one of the pieces of modern equipment employed for fast metal cleaning. It is called the Airless Wheelabrator. The abrasive from an overhead storage hopper is fed to the center of the wheel, whereupon it is hurled, under control, upon the work to be blasted. The final throwing velocity is the resultant of radial and tangential forces. Thus, the blast utilizes all of the power supplied to the blasting unit. The radial velocity is in the direction of the radius of the wheel, and the tangential velocity is tangent to the wheel. The resultant velocity is computed by solving for the hypotenuse of a right triangle whose sides represent the radial and tangential velocities.

The component parts of the blasting unit are indicated in Fig. 1 by letters, and are described as follows: *A*, abrasive feed funnel; *B*, abrasive (metallic shot or grit); *C*, spacers between side plates; *D*, special steel side plates; *E*, cast-alloy blades (removable); *F*, cast-alloy control cage (stationary in operation); *G*, cast-alloy impeller (rotates with wheel). This unit carries the abrasive to the opening in the control cage, where it is discharged to the bladed section of the wheel.

Fig. 1. The Airless Wheelabrator

Courtesy of American Wheelabrator and Equipment Corporation, Mishawaka, Ind.

Fig. 2 shows an installation of a 36" x 42" Wheelabrator Tumblast in the process of cleaning forgings at the Kropp Forge Company in Chicago. The unit shown in Fig. 1 is installed in this tumbling machine. The scale is removed from the forgings at a rapid pace. Thus, a substantial saving in cleaning cost is effected. The surfaces of the forgings are uniformly cleaned in this equipment, and subsequent inspection operations are carried out with ease, since surface defects can be quickly observed on the forgings. It is also possible to machine and grind the cleaned forgings at greater speeds, because the cleaning machine removes the scale and other impurities right down to the bare metal.

Fig. 3 shows an installation of a cleaning machine at the Wyman-Gordon Company in Worcester, Massachusetts. This machine removes scale and other impurities from forged aviation crankshafts, propeller shafts, and other products. The machine consists of the cleaning unit, cabinet, and heavy-duty conveyor system for handling the forgings on a production-line basis. Cleaning time for one of the 550-pound crankshafts or other heavy forgings is only ninety seconds. A steady procession of these large forgings pass through the machine at a continuous rate.

Fig. 2. Wheelabrator Tumblast in Operation

Courtesy of American Wheelabrator and Equipment Corporation, Mishawaka, Ind.

Shot Peening of Forgings. Shot peening is a cold-working method accomplished by pelting the surface of a metal part with round metallic shot thrown at a relatively high velocity. The principle which this process employs is that of surface compression, by which the strength of the metal is improved. The principle has long been understood and applied. As in other cold-working processes, shot peening increases the fatigue strength of the body of metal by subjecting it to stretching, compression, and twisting beyond its elastic limit.

The blast of metal shot, directed against the surface of the product from the blades of a wheel rotating at high velocity, produces a local surface compression where required. Experimental work indicates that the surface compression stress produced by shot peening is several times greater than the corresponding tension stress developed in the interior of the section. When working stresses are applied that would ordinarily impose a tension stress on the surface, that tension is offset by an inherent residual stress in the surface layer. Because fatigue failures are generally caused by tension stresses rather than by compressive stresses, the peening action increases the fatigue life of the product.

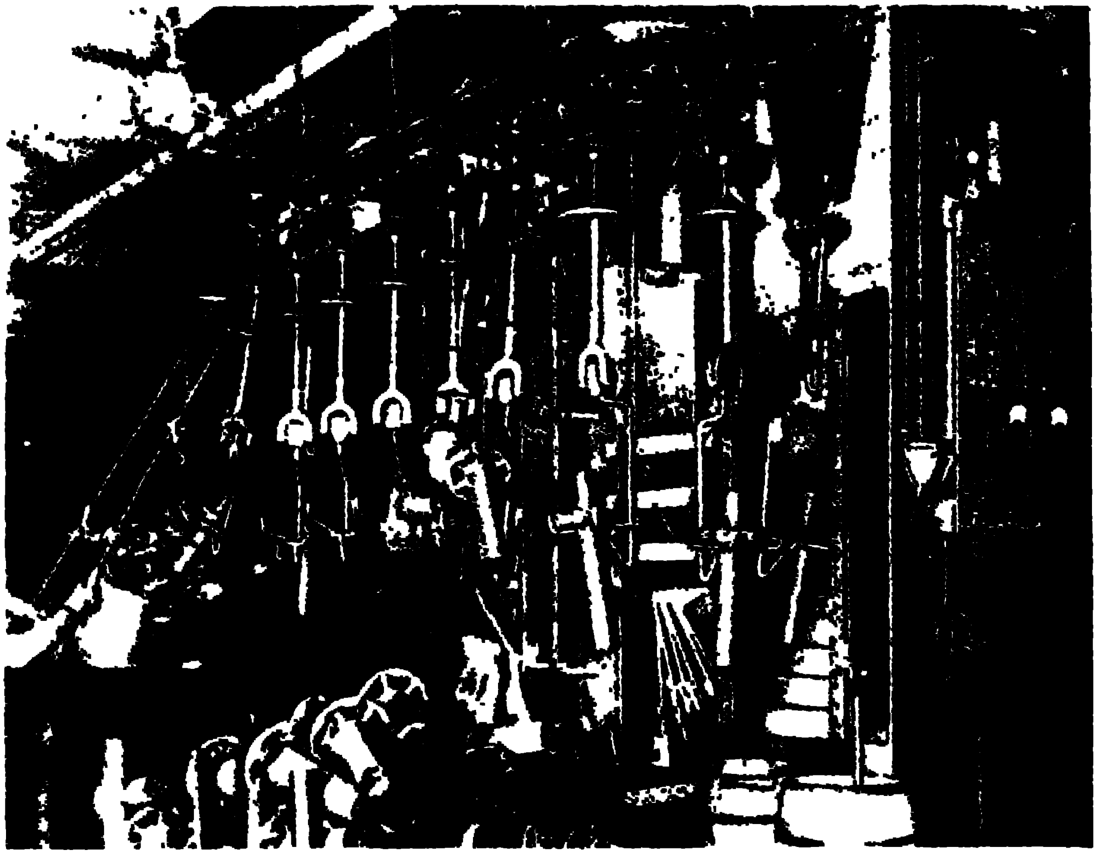


Fig. 3. Cleaning Machine for Removing Scale and Impurities from Forged Crankshafts

Courtesy of American Wheelabrator and Equipment Corporation, Mishawaka, Ind

The result of such action is "pitting" of the surface of the part. Each shot produces the effect of a blow delivered by a small peening hammer. This distorts the surface structure and creates in it a compressive stress 0.005 to 0.010 inch below the surface. These compressive stresses, as stated before, are well balanced by the tensile stresses contained in the metal. Since fatigue failures are generally caused by tension stresses, the compressive stresses offset the harmful effect of the tension stresses. The surface of the cold-worked metal is also strengthened and hardened by the shot-peening treatment. Thus, desirable properties are added to those already possessed by the metal.

The cleaning unit shown in Fig. 1 may also be adapted for shot peening. It can utilize centrifugal force to hurl metal shot at high velocity against the part from the periphery of a rapidly revolving wheel. The blast of metal shot may also be directed against the surface of the product by force of air. Various machine parts, such as shafts, crankshafts, camshafts, connecting rods, gears, and springs can be greatly improved by shot peening, since they can therefore better resist fatigue stresses encountered in hard service. This process can be applied with equal advantage to parts which have irregular surfaces, such parts being difficult to treat by other cold-working procedures. The convenience of application which shot peening affords can be appreciated when local surfaces of such parts as shaft fillets and gear teeth require treatment to offset stress concentration.

Fig. 4 shows an installation for shot peening connecting rods at the Cadillac Motor Company's plant. The work is placed upon a series of independent rubber-covered tables, which are mounted on a main spider that rotates on a central spindle. As the platform turns about its axis, the individual tables are moved successively inside the cabinet. The tables revolve automatically as they approach the blast stream from the blast unit mounted overhead. They continue to do so until they leave the blast zone. Movement of the work in this manner provides uniform coverage of all exposed surfaces. When the tables return to the loading station in front of the machine, the work is turned over, if required, and passed through the blast again to permit peening of the surface not exposed on the first pass.

Additional Operations for Reducing Subsequent Machining. Considerable reduction of rough-machining time and waste of metal are obtainable with forgings, since forging metal in closed-impression dies forms the part close to the contour and dimensions of the finished shape. Often, further reduction in finish-machining time is possible by performing restriking, coining, planishing (finish hammering with smooth-faced hammers or plates), and other operations. These operations size the forging to exact dimensional tolerances and make further finishing-to-shape, such as machining or grinding, either unnecessary or trivial in extent.

Production costs often may be reduced further through savings in the cost of jigs and fixtures, and savings in the time required for tooling up for finish machining of forgings. Designing for forging should, therefore, take into account the requirements for subsequent finishing operations, since it is often possible so to shape a part that intricate or complex machining setups will be avoided.

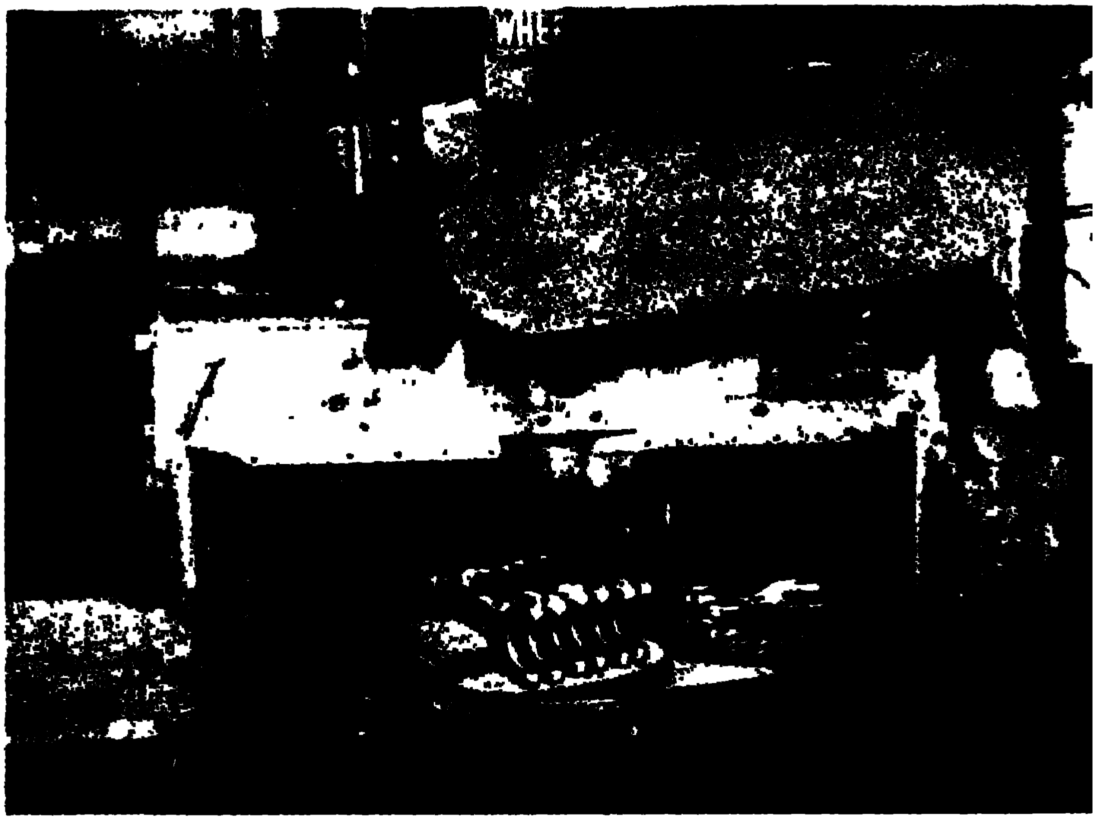


Fig. 4. Shot Peening Connecting Rods

Courtesy of American Wheelabrator and Equipment Corporation, Mishawaka, Ind.

Drop forging of high-temperature alloys has become a highly specialized forging practice. Impetus was given to the development of this practice by the need for providing sufficient fatigue strength and a higher endurance limit for the blade or bucket forgings used on the gas turbines of aircraft jet-propulsion engines. Modern jet engines incorporate these blades in much the same manner that turbosuperchargers, used on reciprocating aircraft engines, do for high-altitude flying. However, the intense heat to which the jet-engine blades are subjected provided the impetus for development and use of the so-called high-temperature alloys, which exhibit high, hot-tensile strength, good ductility, good weldability, and extremely high stress-rupture strength. Blades for the jet engines are produced from these new alloys either by precision forging or precision casting.[1]

When forging these vital parts by the application of new precision-forging techniques, the following physical properties are imparted to the forged products: fatigue strength, high endurance limit, strength and toughness in relation to sectional thickness, and predictable control of grain density and uniformity. Some of the special alloys used for the forged parts do not respond to normal heat-treating methods for developing their mechanical properties needed in strenuous service. To compensate for this disadvantage, a two-step, drop-forging operation was developed in connection with the production of turbine wheels for the turbosupercharger, which operation permitted introduction of a controllable amount of cold working to produce a work-hardening effect. Fig. 5 shows precision-forged blades and buckets for jet engines.

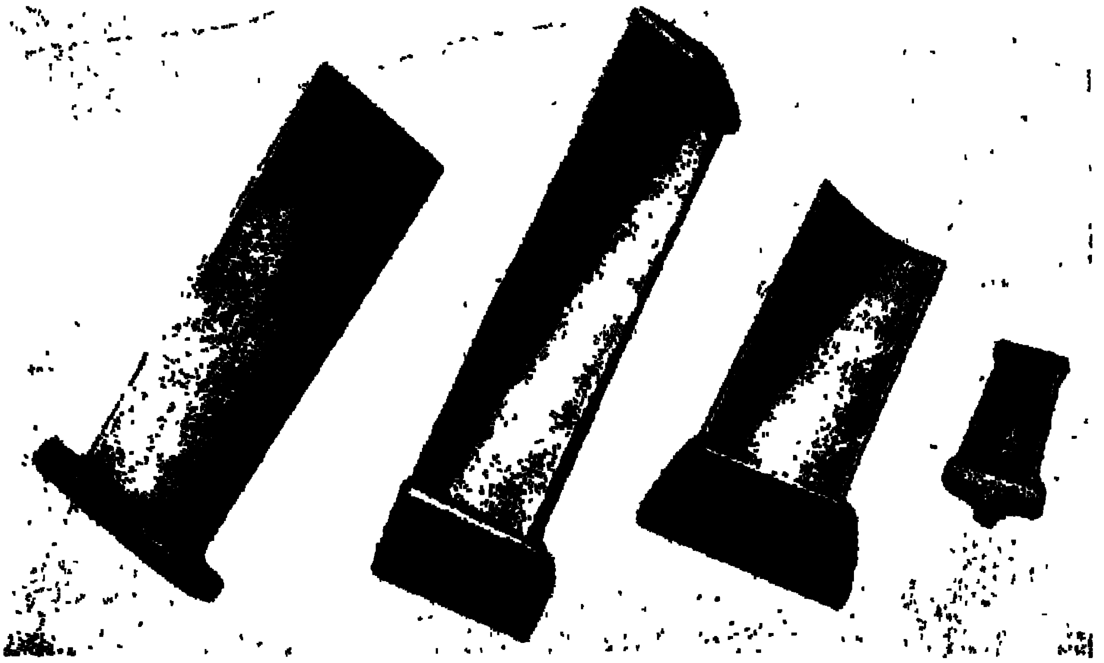


Fig. 5. Forged Blades and Buckets for Jet Engines

Courtesy of American Wheelabrator and Equipment Corporation, Mishawaka, Ind.

In the two-step precision forging operation, hot working shapes the parts, and final cold working insures accurate dimensional tolerances and uniform development of the physical properties. The exact amount of cold working to be done in the finishing die is controlled through proper design of the blocking die, which is used as a first step in the shaping operations. Thus, a commercially uniform cross-section hardness is assured. Successful precision forging of high-temperature alloys is attained by carrying out the following steps: heating control, maintenance of exact alignment of the forging dies, and care in maintaining sharpness and exactness of the die impressions in order to assure the holding of the close tolerances required. Accurate die sinking and finishing operations are necessary to obtain these tolerances, as well as to produce the desired development of physical properties and structural uniformity.

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[1] Discussion of operations for reducing machining in the immediately preceding paragraphs is based upon information contained in *Drop Forging Topics,* published by the Drop Forging Association, Cleveland, Ohio, Volume 13, No. 1, 1948. Adapted with permission.

The manufacturing cycle of precision forging consists of a number of steps of which the first is selection of suitable bar stock that has passed laboratory inspection. The bar is first cut into forging multiples with abrasive cutoff wheels. The stock is then heated to forging temperature in a controlled-atmosphere furnace equipped with pyrometer. Next, fullering or upsetting operations are performed. This provides the correct amount of material in the right locations to insure the complete filling of the die impressions in subsequent operations. Occasionally, the stock must be heated several times before the operation is complete. After cooling to room temperature, the forging blank is cleaned to remove any scale and to permit close inspection for any signs of seams, cracks, folds, or other defects. The blank is then reheated for striking in the blocking dies, where shaping is begun and further directioning and positioning of the inherent fiber-like structure takes place. In the blocking operations, the piece is struck only one or two blows at a time, then hot trimmed and reheated, then struck again. After repeating this cycle of heating, forging, and trimming until the work is down to size in the blocking die, the blade is again allowed to cool and is thoroughly inspected. The heating, forging, and trimming cycle is then resumed in the finishing dies, where the advantages of work hardening in the development of the desired physical properties are obtained. After a hardness check has been made, the forged blades are blasted with a very fine grit, and a nondestructive inspection is made, using Magnaflux or Zyglo equipment.[2] A final inspection, including dimensional check and examination of surface conditions, completes the manufacturing cycle.[3]

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[2] The Magnaflux and Zyglo equipment for nondestructive inspection is manufactured by the Magnaflux Corporation of Chicago. It is recommended

REVIEW QUESTIONS

1. Describe briefly the methods used in removing scale from forgings.
2. Describe the method of cleaning forgings by pickling.
3. Describe the method of cleaning forgings by tumbling.
4. Describe the method of cleaning forgings by sandblasting and metallic shot blasting.
5. Describe briefly the operation of the blasting unit, as shown in Fig. 1.
6. What is meant by shot peening of forgings?
7. Describe the improvement in physical properties of a part subjected to shot peening.
8. What additional operations may be employed for reducing the amount of machining normally required to finish a forged product?
9. Describe precision forging of high-temperature alloys.
10. What physical properties are imparted to products through application of precision forging techniques?
11. Describe briefly the two-step precision forging operation.
12. What are the principal steps in a precision forging manufacturing cycle?

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that the reader consult literature published by the above firm, which explains the use of their various products in detail.

[3] Discussion in this paragraph is based upon information contained in *Drop Forging Topics,* published by the Drop Forging Association, Cleveland, Ohio, Volume 13, No. 1, 1948. Adapted with permission.

CHAPTER XI

Heat Treatment of Forgings

¶ **Heat Treatment of Steel Forgings.** All forged parts, particularly those made from steel, receive a certain amount of heat treatment in the process of being forged and, thereafter, may be used without additional heat treatment. For maximum usefulness, however, many forgings are specially heat treated one or more times before being put into service. Usually, the forgings are heat-treated before and after machining. The purposes of the initial treatment are to secure uniform grain structure of the metal and to increase the ease with which the forged part can be machined. The final treatment makes it possible to use the finished forgings for the service intended. For example, forged tools must be hard and tough; consequently, they must receive final hardening and tempering treatments.

Both the finishing temperature maintained during the forging and the manner of cooling have marked effect upon the product. Fast cooling from a high temperature will result in excessive hardness of the part, and increase the stresses embodied therein, which are caused by the changes in grain structure. Therefore, an annealing treatment, consisting of heating the part to a predetermined temperature in an annealing furnace and then slowly cooling it in the same furnace, is recommended to soften the part in preparation for machining operations. This treatment is likewise appropriate if the coarse grain structure of a part, acquired during the forging (at high temperature), is to be refined. As stated before, the metal has a crystalline (grain) structure. If a fine grain structure is desired, it can be obtained by heat treatment. No matter what type of heat treatment is carried out, it consists essentially of controlled heating and cooling of the product in the solid state to secure the properties specifically demanded. These operations are conducted in furnaces especially designed for the treatment to be applied and the forging to be produced. For recommended heat-treatment temperatures and other important characteristics of metals, see Table III at the end of this chapter.

Annealing of Steel Forgings. Although annealing is a process that is chiefly used to effect softening of a piece of metal, it is also used to remove internal stresses, eliminate gases, and improve the physical and mechanical properties of a forging. The operation consists of first heating the forging in an annealing furnace up to or beyond the critical temperature of the metal, which may range from 1300° to 1650° F., depending upon the grade of steel making up the piece, and the specific purpose for which the forging is being annealed. The forging is kept at points within that range for a scheduled period of time, and then is allowed to cool slowly in the furnace. The predetermined heating temperature, as well as the rate of cooling, is maintained uniformly throughout the annealing operation.

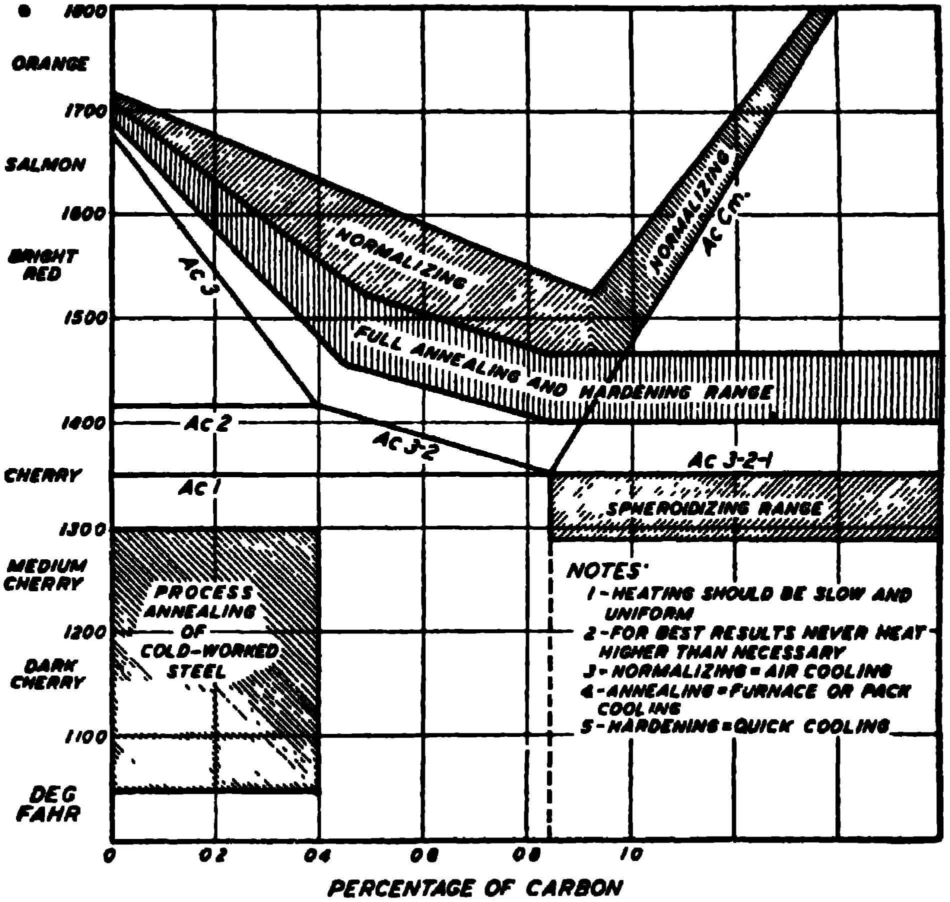
Properly executed annealing will accomplish the following results: remove strains accumulated during various forging operations —strains resulting from pressures exerted on the metal, make the part softer for machining or grinding, change its ductility, refine its grain structure, and produce a definite structure in the metal. The treatment must, of course, follow the proper procedure for the type of steel involved. Otherwise, serious harm may be done and the part ruined. If the forged part is to be machined or ground prior to hardening, it must be annealed. The process should be carried out in such a manner as to protect the steel from scaling and decarburization as far as possible.

To prevent excessive decarburization and scaling, annealing of high-grade forgings should be done in furnaces with controlled atmosphere, or in well-sealed packed containers in ordinary furnaces. If containers are used, they should be packed with carbonaceous material (charcoal, gaseous and liquid solutions containing carbon, etc.) recommended for the purpose. Either method requires slow heating from a low temperature to the proper temperature, and an allowance of sufficient time at that temperature for the heat to penetrate to the center of the forging. The cooling of the forging is carried out slowly, usually in the furnace. When containers are used, they are sometimes removed from the furnace while hot, and allowed to cool in either dry ashes, lime, or other retardant medium. The latter method of slow cooling is especially recommended for tool-steel forgings immediately after forging operations. Most tool steels have some air-hardening properties, and therefore must be cooled slowly from the forging temperature. The forged part should be protected from moisture and draughts by burying it in one of the above-described retardant mediums.)

(**Normalizing of Steel Forgings.** The treatment used to produce a uniform structure and grain refinement after forging and rolling is known as *normalizing*. This treatment is also given the forging if the steel shows signs of overheating, and if little is known of its history previous to this stage. It consists of heating the piece to about 100° F. above its critical temperature, and then cooling it in air at atmospheric temperature. Normalizing between the forging and annealing operations is strongly recommended for some grades, because it puts the steel in a condition to respond better to subsequent operations. The critical temperatures of metals are those at which the physical properties of the metals change. Metals are made free to begin recrystallizing (changing in grain structure) when they are heated to their critical temperatures. Fig. 1 is a critical-temperature diagram that shows visual normalizing, annealing, and hardening ranges.

To get the most beneficial effect from the normalizing treatment, the forging should be slowly heated to the temperature indicated above, and held at that temperature for sufficient time to be heated uniformly throughout, and then air-cooled. However, on account of air-cooling, there is a possibility for development of cooling stresses, which are not as severe as those developed during the forging operation. They may be relieved by an annealing process which should follow immediately. High-carbon and high-alloy grades of tool steel are easily hardened in air, and are subject to dangerous cooling stresses. Therefore it is best not to normalize them unless the heat treater has sufficient knowledge, acquired by practice and study, of proper handling of these steels. Normalized forgings are easy to machine, though not quite as easy as forgings that are annealed. On the other hand, the tensile strength and yield point of a normalized forging is higher than an annealed one.)

(**Hardening of Steel Forgings.** Hardening is accomplished by heating the steel forging slightly beyond the critical temperature of the steel, and then causing it to cool rapidly. The cooling consists of quenching the hot steel in a liquid such as water, brine, or oil. In earlier days, steel was heated in a simple forge fire until the color of the steel turned to a full red. In order to check whether the correct heating temperature of the steel has been reached, a magnet was applied to it, since steel at or above its critical temperature is non-magnetic. In modern heat treatment, practically all the heating for hardening is carried out in furnaces designed to heat the steel to the proper temperature. Many of these furnaces are designed to control not only the temperature, but also the atmosphere in which the steel is heated.



NOTES:
1-HEATING SHOULD BE SLOW AND UNIFORM
2-FOR BEST RESULTS NEVER HEAT HIGHER THAN NECESSARY
3-NORMALIZING = AIR COOLING
4-ANNEALING = FURNACE OR PACK COOLING
5-HARDENING = QUICK COOLING

Fig. 1. Critical Temperature Diagram Showing Visual Normalizing, Annealing, and Hardening Ranges

The many and varied compositions of steel require different temperatures for hardening. These temperatures range from 1400° F. for the carbon steels to 2300° F. for the high-alloy steels. Irrespective of the grade, all steels should be heated slowly and uniformly. If the hardening temperature of the steel is above 1800° F., it should be preheated in a separate furnace or preheating chamber to between 1600° and 1700° F., and then brought rapidly up to the hardening temperature in the hardening furnace. Heating to higher temperatures than those recommended by long experience, or holding the part in the furnace longer than necessary, will have harmful effects. If salt or lead baths are used, the heating time required is reduced to about one-half the time needed for heating the part in a hardening furnace. However, the part being treated in the baths should be warmed before immersing them in the heating medium. The salt or lead baths are tanks containing these media in a molten state. The temperatures of these media are high enough to heat-treat the required metals.

During hardening, steel undergoes actual volume changes which set up severe stresses that may cause breakage unless relieved. This is especially true in the case of forged tools, and tempering should start immediately after the hardening operation, preferably before the part has cooled to room temperature. The steel tool should be allowed to cool in the quenching medium to at least 200° F.

There are several methods of rapid cooling or quenching of the heated steel. The method selected for best results depends upon the type of the steel, service requirements, and available treatment facilities. The cooling or quenching media may be water, brine, salt or lead baths, still air, and blast air. When a liquid quenching medium is used, its temperature should be maintained between 70° and 100° F. In the case of forged tools and other precise products, it is desirable to pack-harden the parts to be treated to prevent surface deterioration (chiefly caused by oxidation and contact with undesirable gases). The parts are packed in containers with protecting materials, such as cast-iron chips, or sand, before charging in the furnace. After proper heating, the parts are cooled in the desired medium.

Tempering or Drawing of Steel Forgings. This is a heat-treating operation that is carried out after the steel forging has been hardened in the usual manner. The operation consists of heating the hardened part for a scheduled period to an indicated temperature in the range between room temperature and the critical temperature of the steel. The treatment is followed in most cases by air-cooling. The rate of cooling of the heated steel is of no great importance in tempering. Fully hardened steel forgings are not often used in actual practice because of their brittleness. The tempering, if successfully carried out, converts the hard and brittle steel into a metal that is found useful in many applications.

Properly hardened steel may be converted into a metal possessing maximum hardness, minimum ductility, smallest grain size, and a minimum amount of internal stress and strain. These properties are, in many cases, not sufficient to meet conditions imposed upon the products. Therefore, tempering is done for the purpose of converting the hardened steel into a metal that, though of reduced hardness, is stronger and tougher by benefit of the treatment received. Tempering, properly applied, relieves internal stresses, and stabilizes the structure of the metal.

The temperature at which a forging is tempered is determined by the subsequent processing operations, the service for which it is intended, and its analysis. Some forgings made of carbon steel may be tempered at low temperatures of about 300° to 500° F. Forgings from high-alloy steels may require tempering temperatures of from 900° to 1200° F. If the forged product is subjected to high temperatures in service, it should be tempered at temperatures higher than those encountered in actual service.

Tempering operations are conducted in fully automatic air-tempering furnaces, where the air is heated by gas or electricity to the desired temperature. The air, when heated, is circulated around the parts being tempered. Liquid baths containing hot oils, molten salts, and molten lead may be employed instead of furnaces for the purpose of heating the parts to their proper tempering temperature. The parts are immersed in the hot bath for a definite length of time, and are then cooled in still air to room temperature.

Color Oxides. Nature has provided a very useful indication to a certain degree of the temperature of steel heated to low temperatures, such as in the tempering operation, through the formation of a surface film of oxide colors, which are films of oxide of iron of varying thickness. If a piece of carbon steel is polished and then slowly heated, the brightened surface will take on what are known as *temper colors.* These colors form on steel that is polished, regardless of its physical condition. At most, they are only rough indicators of the actual temperature. At least, they indicate the temperature of the surface of the steel. If the center of a part in question is to be subjected to service, time must be allowed to insure that the center of a part reaches the same temperature as that prevailing at the surface of the tool. Table II gives approximate suggestions as to the color which may be expected at different temperatures on heating. The table also suggests some of the practical uses corresponding to the different tempering temperatures.

TABLE II. TEMPERATURES INDICATED BY TEMPERING COLORS

Degrees Fahrenheit	Color	Suggested Uses
430	Faint Straw	Scrapers, taps, paper cutters
460	Dark Straw	Boring cutters, punches, dies
500	Dark Brown	Twist drills, rock drills, hammer faces, augers
540	Light Purple	Axes, wood carving tools
570	Dark Blue	Iron and steel chisels, knives
610	Light Blue	Springs, screwdrivers, saws for wood
630	Steel Gray	Springs

Induction Hardening. Many steel forgings are given a heat treatment that develops a hard wear-resisting surface and, at the same time, retains a soft, tough core. Such a condition is obtained when low-carbon steel forgings are subjected to either a carburizing or nitriding case-hardening treatment. The carburizing heat treatment consists of heating the metal in contact with media containing carbon. The nitriding treatment employs ammonia gas (NH_3). Nitrogen is added to the surface of the steel, from the ammonia gas, the body of metal being heated to the proper temperature ranging 850° to 1150° F. in a furnace designed for this purpose. However, forgings made of a steel high enough in carbon to quench-harden may be given a suitable heat treatment which results in only surface hardening or but slight penetration hardening of the forging. Several methods may be employed for accomplishing good results in surface hardening. Two of those methods are in widest use: (1) electric induction heating of the surface of the forging followed by quenching, and (2) local heating of the surface of the forging with a hot flame followed by quenching.

The induction surface-hardening process, known as the *Tocco process*, was developed by the Ohio Crankshaft Company of Cleveland, Ohio. Heating is obtained by employing an inductor block or heating coils, and passing a high-voltage current, which is transformed into a current of low voltage and high amperage, through the inductor block or coils surrounding the surfaces to be hardened, but removed from actual contact with them. The coils induce a current in the surface of the steel which rapidly heats the metal to any temperature desired. With proper control of the high-frequency current and the time of exposure, the temperature indicated may be that required for hardening. After reaching the hardening temperature, the electric circuit is opened and the heated surface of the metal is rapidly quenched by a fine spray of water supplied from a water jacket which is conveniently located inside or outside the inductor block or coil.

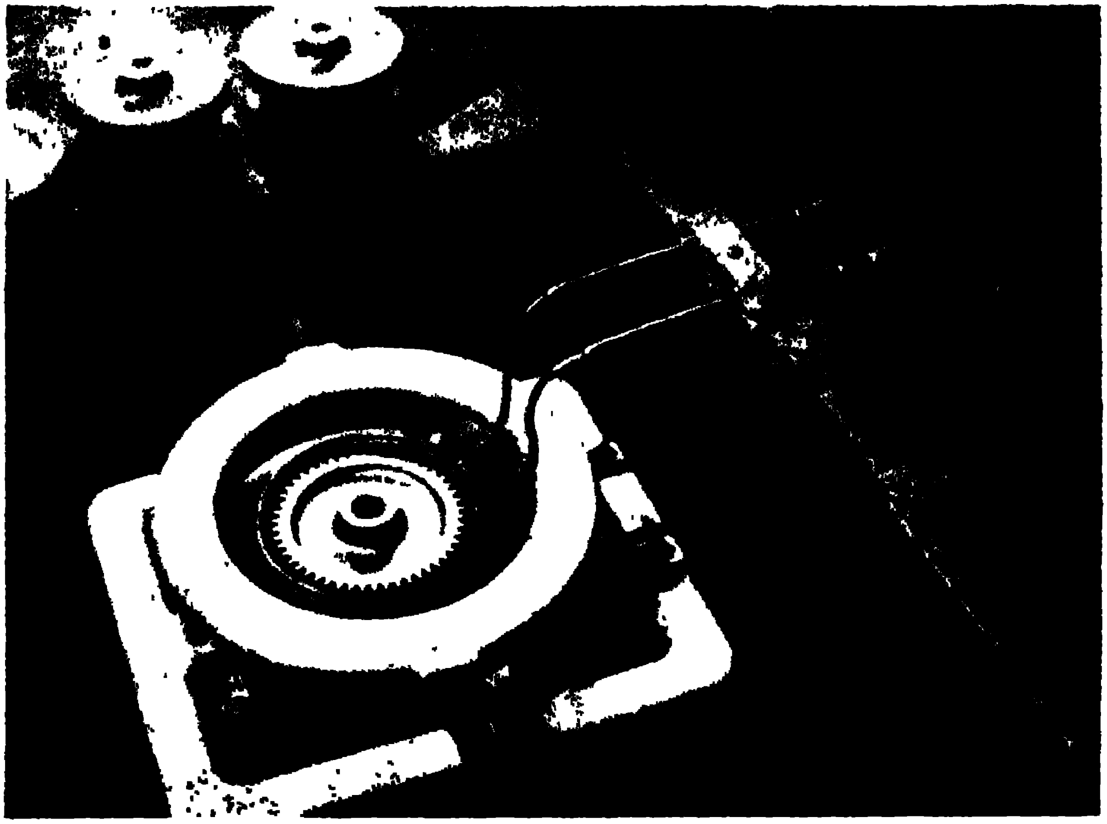


Fig. 2. Induction Setup for Surface-Hardening a Gear

Courtesy of Massachusetts Steel Treating Corporation

Fig. 2 shows the hardening of a gear by this method. The gear rotates between the heating coils and is quenched by water from the jacket surrounding the coils and the gear.

Fig. 3 shows a setup for hardening the surface of a grinding machine spindle by the induction process. Upon reaching the correct hardening temperature, the spindle is removed and quench-hardened.

The time required for performance of the steps of the hardening cycle is but a few seconds. Proper heat control and rapid pressure quenching insure a surface hardness that gradually blends into the soft core not touched by the heat. Many carbon and alloy steels may be successfully surface-hardened by the induction method, but they must contain a reasonable percentage of carbon in order to be properly quench-hardened.

The process of surface hardening by induction is rather expensive for short runs of production, since the equipment, consisting of special inductor blocks or coils, must be designed to suit each product. Likewise, automatic timing must be arranged to suit the particular job. However, when large quantities of identical parts are to be surface-hardened, this process is economical and efficient, because of the short time-cycle involved and the uniformity of surface hardness achieved. Fig. 4 illustrates the results obtained when using this process, particularly the uniform hardness penetration or case hardening achieved.

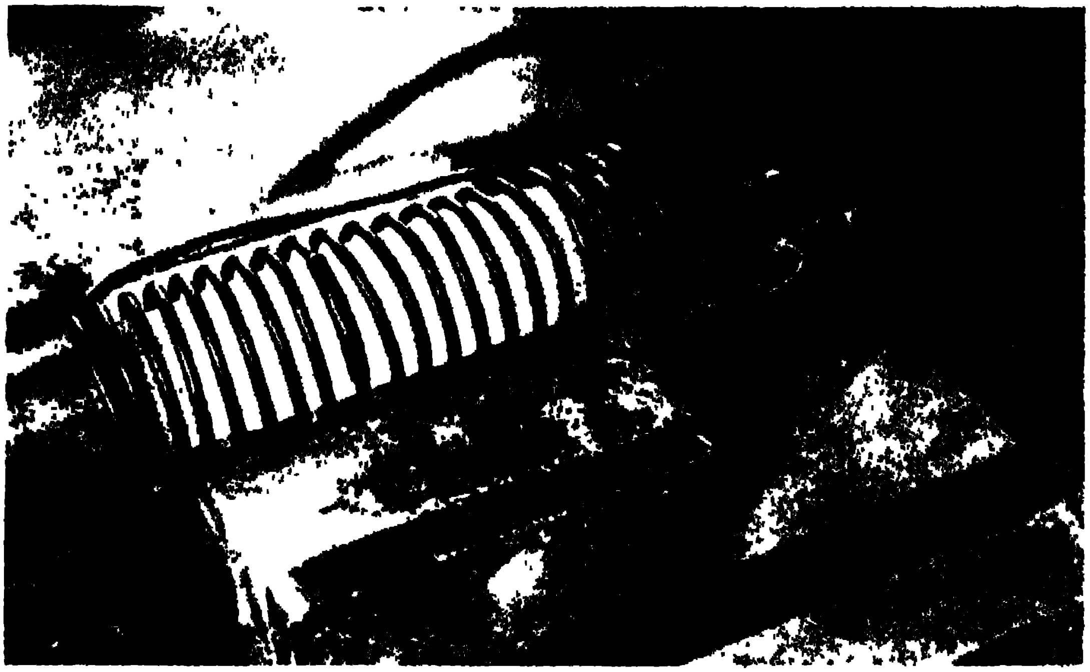


Fig. 3. Induction Coil Used To Surface-Harden a Grinding Machine Spindle

Courtesy of Massachusetts Steel Treating Corporation

Crankshaft bearings and similar wearing surfaces, such as transmission shafts, camshafts, connecting rods, gears, spindles, cylinders, etc., may be successfully surface-hardened by the induction process, provided that large production of identical parts warrants the expense of providing the special equipment. Important advantages of this process over other hardening processes are close control of the heating zone, uniformity of the hardness penetration, and the small amount of distortion produced in the heating cycle.

Flame Hardening. This is a surface-hardening process which imparts to the treated objects those hardening properties that would be difficult and expensive to secure by other heat-treating processes. For example, it is impractical to surface-harden grey cast-iron machine parts by heating them in a furnace, and then quenching them in water or brine, because, when this is done, warpage, distortion, or fracture is likely to occur. For the same reason, it is difficult to surface-harden large cast-iron or steel sections by the usual methods. Flame hardening, however, can be successfully applied to surface-harden such parts.

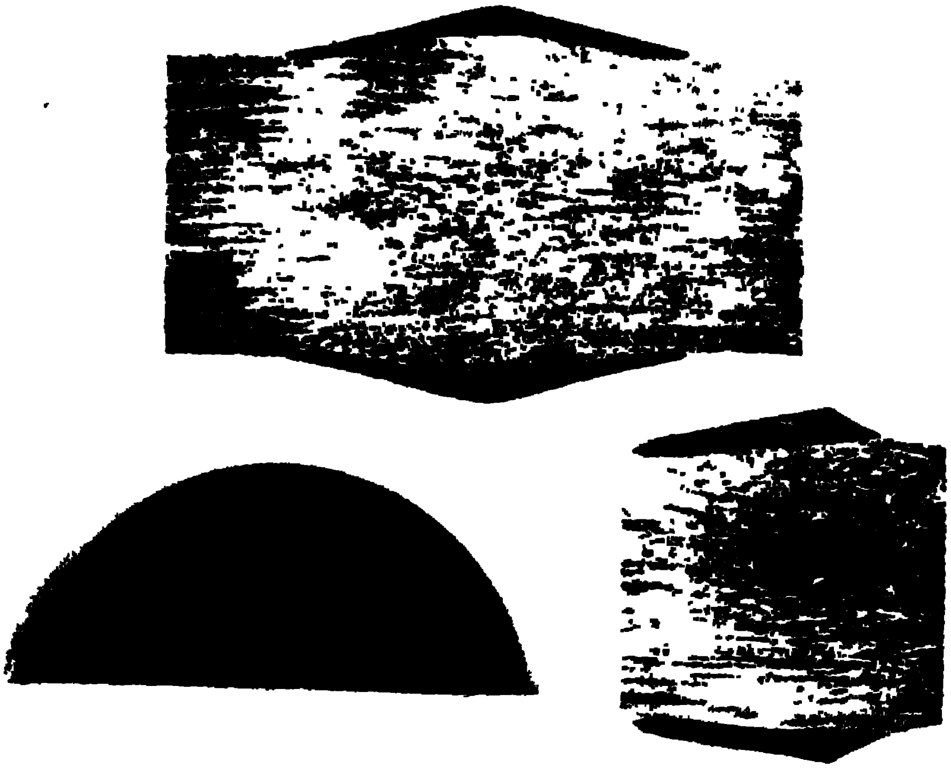


Fig. 4. Etched Sections of Shafting Showing Case-Hardened Effect Obtained by Induction Heating

Courtesy of Ohio Crankshaft Company

The process of flame hardening consists of applying heat to the metal surface by use of an oxyacetylene flame, only a thin layer of the heated surface being affected and brought to the hardening temperature. The torch is moved slowly forward along the part receiving treatment. A stream of water follows the path of the flame, quenching and hardening the surface as rapidly as it is heated. The depth hardness is controlled by adjusting the speed of the moving torch.

Various methods may be employed in flame hardening, such as methods using the oxyacetylene torch or other suitable heating mediums. Procedure depends upon the size and shape of the object.

Small parts may be heated individually and then quenched. Parts of cylindrical shape may be slowly rotated and heated by exposing their surfaces to the flame of the torch or gas burners, as shown in Fig. 5.

When the hardening temperature is reached, and when the heat has penetrated the part to the desired depth (which may be 0.010" to 0.125", depending upon the service in which the part will be used), the quenching operation follows. This procedure produces a hard surface. The core, unaffected by the heat, remains soft. The gear shown in Fig. 5 is flame-hardened by rotating it in the presence of gas burners. When the gear teeth reach the correct hardening temperature (see Fig. 1), the gear and the rotating table are lowered into the quenching tank, which forms a part of the unit. It is recommended that the carbon content of the steel should be between 0.40 per cent and 0.70 per cent. Special low-alloy steels also may be flame-hardened. Parts which may be flame-hardened successfully include: machine-tool beds, rail ends, gears, cams, and camshafts.

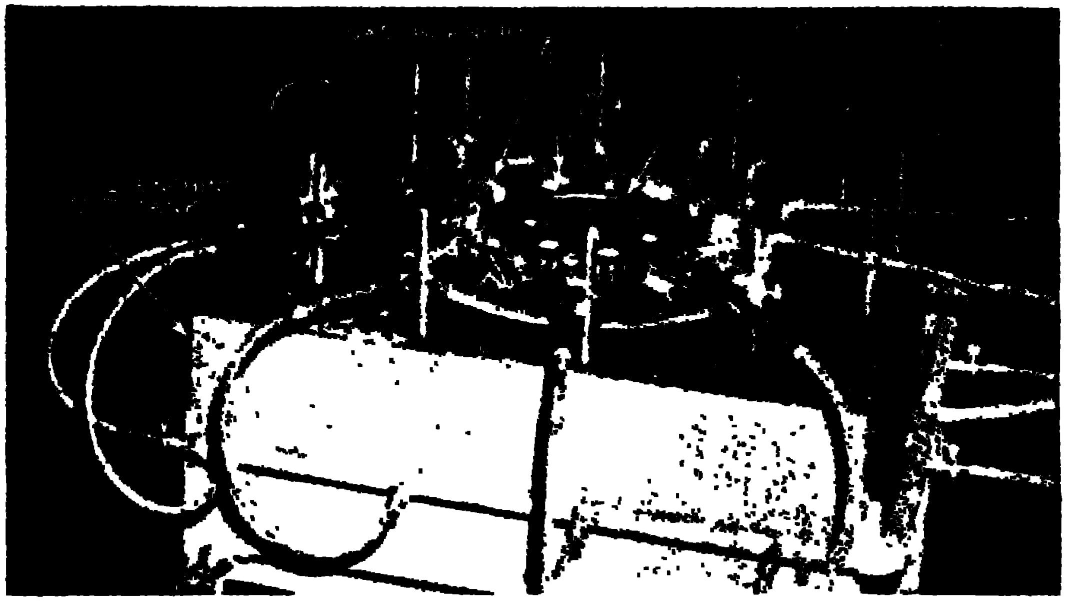


Fig. 5. Flame-Hardening Machine

Courtesy of Massachusetts Steel Treating Corporation

Other Heat-Treatment Methods for Steel Forgings. Many steel forgings are given other heat treatments besides the treatments previously described in this chapter. Hard wear-resisting surfaces can also be developed by subjecting low-carbon steel forgings to either a carburizing or nitriding case-hardening treatment while, at the same time, a soft, tough core is retained. Among these treatments, cyaniding and nitriding have a wide application.

Cyaniding is a liquid-bath carburizing and hardening process which employs molten salts as carburizing and nitriding agents. Those most commonly used salts are potassium cyanide (KCN) and sodium cyanide (NaCN). Small parts made from low-carbon steel may require only a surface hardness, with a hardness penetration as shallow as a few thousandths of an inch. Furthermore, only small portions of these parts may require hardness treatment. Such parts may be carburized and fully hardened on their surfaces by immersing them in a cyanide, liquid bath.

The steel to be surface hardened (case hardened) is placed in the molten salt bath. A typical bath contains over 25 per cent sodium cyanide heated to about 1550 F. At this temperature, the steel will absorb carbon and nitrogen from the bath to a depth of about 0.005 of an inch in a period of 15 minutes. A penetration of 0.010 of an inch will be achieved in one hour. The absorbed nitrogen is present in the outer skin, or case, in the form of finely dispersed iron nitrides that make the surface of the steel hard and brittle. To fully harden the surface of the steel, it is rapidly quenched direct from the cyaniding temperature in water or brine.

To avoid distortion, the carburizing temperatures are either lowered or the heated metals are cooled a certain amount before being plunged into the quenching solution of water or brine. The parts must be free of moisture before being immersed in the molten salt bath, so that violent spattering of the hot metal will be avoided. Ample protection must be provided the operator by requiring that goggles, gloves, and helmet be worn, as the situation demands. A suitable hood, which shields the molten salt bath, and an exhaust system provide protection for the operators from the dangerous and obnoxious fumes which are given off by the bath.

Nitriding is a heat-treatment process employing ammonia gas (NH_3). Nitrogen is added to the surface of the steel, while the body of metal is being heated to the proper temperature in a furnace of suitable kind. Carbon does not greatly influence the surface hardness of the heat-treated steel, but affects only the core in the finished nitrided steel. The nitriding temperatures keep within a range of from 850° to 1150° F., which is far more moderate than the range indicated for carburizing operations. The most satisfactory nitriding results are achieved at a temperature of approximately 950° F.

Nitriding is not suited to the low-carbon steels, which are so conveniently case-hardened by the carburizing process. Rather, the process is limited to special-alloy steels. The parts subjected to nitriding are previously machined and, in many cases, already heat treated. Once a surface hardness is achieved, no further treatment is necessary. The properties imparted to steel by nitriding include: wear resistance, retention of hardness at high temperatures, and some resistance to corrosion.

The nitriding operation is carried out in special muffle-type furnaces through which ammonia gas is passed in order to introduce nitrogen to the heated steel. The ammonia gas entering the furnace partially breaks down into a nitrogen and hydrogen gas mixture. The free nitrogen, being very active under these circumstances, combines with the iron and other elements present in the steel, and forms finely dispersed particles of nitrides that impart a high degree of hardness to the surface of the steel.

Spheroidizing is another type of annealing heat treatment. The operation, which is similar to ordinary annealing, consists of heating the steel to the critical temperature range or somewhat below. The heating period is of several hours' duration, and the heating is followed by slow cooling to approximately 1000° F. A thorough soaking (absorbing heat throughout the entire body of metal) of the steel at the annealing temperature is necessary before proceeding with subsequent operations, such as first cooling to 1000° F., and finally cooling to room temperature.

Carbon, which has an important influence on the physical properties of steel, does not exist in the metal in the free state, but rather as an iron carbide called *cementite* (Fe_3C). Cementite gives the steel its hardness and strength, and is responsible for the ability of the steel to receive heat treatment. At the annealing temperature, the hot cementite is out of solid solution with the iron, and forms into small globules, or spheres, that take permanence of form in the period of slow cooling. The rate of cooling is about 100° F. per hour. The globular structure in steels is cementite, and the remaining structure is *ferrite* (soft iron).

One of the important benefits of spheroidizing is its conditioning of steel for machining, the effect being contrary to that produced by annealing. Tool steel, for example, when annealed by the ordinary method, becomes difficult to machine. Such steel is made much more machinable by spheroidizing. Tool steels of either the high-carbon or high-alloy types may now be machined with fair ease by benefit of this treatment.

Chapmanizing is a process which differs somewhat from cyaniding. It employs ammonia gas in addition to the molten cyanide bath. The dissociated ammonia gas is bubbled through the molten cyanide bath, thus increasing the amount of nitrogen present.

Heat Treatment of Nonferrous Forgings. Nonferrous forgings may be heat-treated in order to acquire additional physical properties, or to improve those already existing in the metal. Pure copper may be hardened by cold working, and copper alloys may be hardened and strengthened by cold working and heat treatment. Pure copper and copper alloys may also be annealed for the purpose of restoring their natural ductility and softness, qualities which may have diminished as a result of previous cold-working operations. Annealing copper or its alloys consists of heating the metal to a temperature of about 1100° F., holding it at this temperature for a definite length of time in order that the heat may penetrate it uniformly throughout, and then permitting the metal to cool to room temperature without regulation of the rate of cooling. The original grain structure of the metal completely changes at 1100° F. without promoting grain growth of appreciable amount.

Brass may be annealed after cold working. The process of annealing brass consists of heating the cold-worked brass to about 1100° F., which is above its recrystallization temperature, and then cooling it to room temperature. Internal stresses produced by the cold-working operations may be removed from the brass by this heating. The annealing removes all traces of the previous cold-worked state of the brass, and restores its original ductility. The rate of heating and cooling have no appreciable effect on the grain size of the metal.

Annealing also corrects the hardening effects that cold working produces in bronze. This corrective annealing is done by heating the metal to a temperature above the recrystallization point, and then cooling it at any convenient rate. Aluminum bronze may be hardened by heating the metal to a point above that of recrystallization and cooling it rapidly thereafter. This heat treatment, which not only hardens the metal but strengthens it also, makes it possible for hand tools, such as chisels, screwdrivers, and wrenches, to be used under conditions where nonsparking is desirable because of the danger of fire or explosion. Oil refineries and other industrial plants in which inflammable or explosive materials are used and stored, require the use of nonsparking tools. Many aluminum bronzes have been developed, the strength and hardness of which may be increased considerably by heat treatment similar to that employed in the treatment of aluminum-copper alloys.

When aluminum alloys are cold worked, strain hardening results, i.e., the resultant strain tends to harden the metal. The annealing process provides a means of eliminating the condition. This process is carried out by heating the metal to some definite temperature that permits recrystallization of its structure, and then cooling it to room temperature. The heating temperatures may vary from 650° to 750° F. The rate of cooling that should be allowed depends upon the type of aluminum alloy being treated.

Another heat treatment of aluminum-copper alloys, called *solution heat treatment*, depends upon the changing solubility of aluminum for the constituent $CuAl_2$ during heating and cooling of the latter in a solid state. If an annealed aluminum alloy containing 4.5 per cent copper (Cu) is reheated to a temperature of about 950° F. for 14 hours, most of the $CuAl_2$ present in the annealed alloy will have dissolved. When this solid solution structure is quenched rapidly in water, most of the $CuAl_2$ will remain in solution in the metal.

This treatment improves the corrosion resistance of the aluminum alloy, and increases its tensile strength as well. The strength of the alloy may be increased further by a cold-working operation following the solution heat treatment. Molten salt baths, such as one of fused sodium nitrate, furnish satisfactory heating media affording the necessary temperature control. Air furnaces, wherein temperature uniformity may be obtained by means of forced-air circulation, may also be used. Temperature control may be maintained with the aid of temperature-recording instruments. Such devices provide an accurate record of the temperature held throughout a heating cycle. Fig. 6 shows a typical heat-treatment operation as applied in airplane-parts production.

Another heat-treating process, known as *precipitation hardening*, achieves an increase in strength of an aluminum-alloy product treated by a gradual precipitation of minute particles of the constituent $CuAl_2$, this action taking place in a solution-heat-treated alloy with aging at room temperature. The precipitated particles function as keys, and produce considerable resistance to "slip" (shifting about of the minute crystals in relation to one another). Thus, the strength of the metal is increased substantially. For example, if an aluminum-copper alloy is undergoing a solution heat treatment, its strength increases rapidly, even from the first hour. After five days, the strength has increased to about 62,000 p.s.i., with no change in elongation. Precipitation hardening produces an aluminum alloy whose strength is near that of structural steel, though its weight is only one-third as great. Precipitation hardening, at room temperature, may be postponed by cooling solution-heat-treated aluminum alloys to temperatures below 0° F., and holding them at those low temperatures as long as desired. This property is utilized in the treatment of aircraft parts, which are solution heat treated and then placed in a refrigerator until the time for processing or assembling operations arrives. Thereupon, the parts are allowed to age-harden at room temperature.

Heat-Treating Furnaces. Various types of furnaces have been developed for heating steel in order to give the metal the treatment proper to specific needs and conditions. The type of treatment to be applied, the size and shape of the product, and the volume of production anticipated, together with considerations of efficiency and economy, are the factors which determine selection of a furnace.

Fig. 6. Propeller Blades Suspended in Rack for Heat Treatment

Courtesy of Aluminum Company of America, Pittsburgh, Pa.

Batch-type or continuous furnaces are recommended for various heat-treating operations on a large production basis. These furnaces are equipped with devices which provide automatic control of specific conditions, such as temperature, composition of atmosphere (gaseous content of the furnace enveloping the work), etc. Mechanical devices also are provided for handling parts as they enter and emerge from the furnace, and for plunging these parts into the quenching baths and removing them therefrom. For efficient operation, many furnaces are designed for applying treatment by one process only, a factor which makes for economy in the item of labor. Fig. 7 shows a battery of fuel-fired batch-type furnaces complete with gantry frame for handling heavy forgings or castings as they enter and leave the furnaces. Quenching equipment also is shown.

Installations of this type are ideally suited for annealing and normalizing or heating and quenching forgings, castings, plates, sheets, coiled strip, and other products of similar kind.

Furnaces may be oil-fired, gas-fired, or electrically heated. They may also be (1) the direct-fired type, in which the steel is allowed to come in contact with the hot gases of combustion; (2) the semi-muffle type, in which the gases of combustion are deflected from the parts being treated, while circulating around them, and (3) the full-muffle type, in which a separate chamber is provided for the parts to be treated. The gases of combustion circulating within the chamber are prevented from coming in contact with the parts.

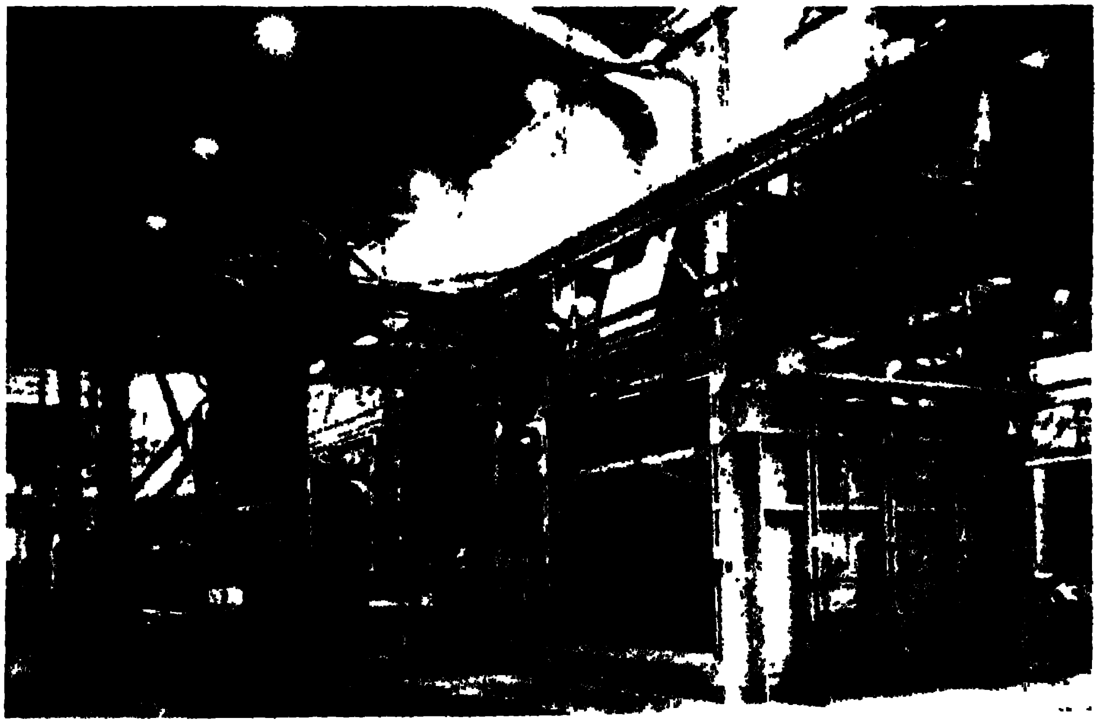


Fig. 7. Battery of Fuel-Fired Batch-Type Furnaces Complete with Quenching and Materials-Handling Equipment

Courtesy of The Electric Furnace Company, Salem, Ohio

Electric furnaces are equipped with resistors which are placed around the muffler for the purpose of heating this unit and the steel contained within it. To obtain maximum protection from oxidation, a furnace of controlled-atmosphere type is used in conjunction with full muffling.

Recent development makes it possible to use electric furnaces with muffling, in which a controlled atmosphere serves to prevent the oxidation of steel surfaces, the formation of scale and decarburization, or the loss of surface carbon during the heating cycle. This is accomplished by adding artificial gas atmospheres to the heating chambers of the furnaces. The gas mixtures commonly employed include large quantities of CO or H_2, which are excellent reducing gases that prevent decarburization. Fig. 8 shows an electrically heated *Hydryzing* furnace that employs a neutral controlled atmosphere for hardening all types of steel without causing scale to accumulate or effecting decarburization.

Fig. 8. Electrically Heated Rotary-Hearth Hydryzing Furnace

Courtesy of Lindberg Engineering Company, Chicago, Ill.

The surfaces of the heat-treated parts come out clean. Therefore, costly clean-up operations are avoided. Various types of furnaces, generally similar to the one shown in Fig. 8, are used for these operations. The types include: rotary hearth, rotary drum, belt conveyer, and tilting hearth. These furnaces have been developed for large production runs, as well as for toolroom work and for brazing operations.

Liquid Heating Baths. Immersion heating (liquid baths) has many distinct advantages which make it desirable for routine hardening and tempering operations. It makes rapid and uniform heating of parts possible. It prevents scale, thus eliminating subsequent cleaning operations, and helps to prevent warping or cracking of intricate sections. Three types of heating baths are in common use. They are classified in *Tool Steel Treaters' Guide*[1] as follows:

1. Oil ....temperatures up to 600° F.
2. Lead ......temperatures ranging from 650° to 1600° F.
3. Salts ......temperatures ranging from 300° to 2400° F.

Oil baths are used for low-temperature tempering operations where it is not necessary to exceed 600° F. As this temperature is approached, increasing difficulty will be encountered in controlling the bath and, at the same time, a gum deposit that is apt to form on the work. Hot caustic solution or kerosene may be used for removing this objectionable deposit. Oil baths at high temperatures are also fire hazards and should be avoided.

Lead baths have a high heating rate, and are used mainly for tempering alloy and high-speed steels. They may also be employed for other heating operations where temperatures do not exceed 1600° F. The lead bath must be protected by molten salts or charcoal, since molten lead oxidizes rapidly.

Salt baths are used for a wide range of temperatures. Suitable salts are commercially available in the prepared form for use within the different hardening or tempering ranges. These baths are easily controlled at the desired temperatures, and effectively prevent scaling. Ferrous as well as nonferrous metals and alloys are treated in salt baths.

Molten lead and molten salt baths may be used successfully for heating steel in heat-treating operations involving annealing, hardening, tempering, etc. When molten lead is used, the steel may be protected from "lead sticking" by coating it with a thin film of salt or other suitable material before immersing it in the lead bath. Coating of the steel may be accomplished by dipping the metal, while warm,

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[1] Booklet 148-B, published by Bethlehem Steel Company, Bethlehem, Pennsylvania, 1942.

Fig. 9. Salt Bath Equipment for Case Hardening

Courtesy of E. I. du Pont de Nemours and Company, Wilmington, Del

in a brine solution, and then allowing it to dry. This leaves a coating on the surface of the steel that serves to prevent "lead sticking."

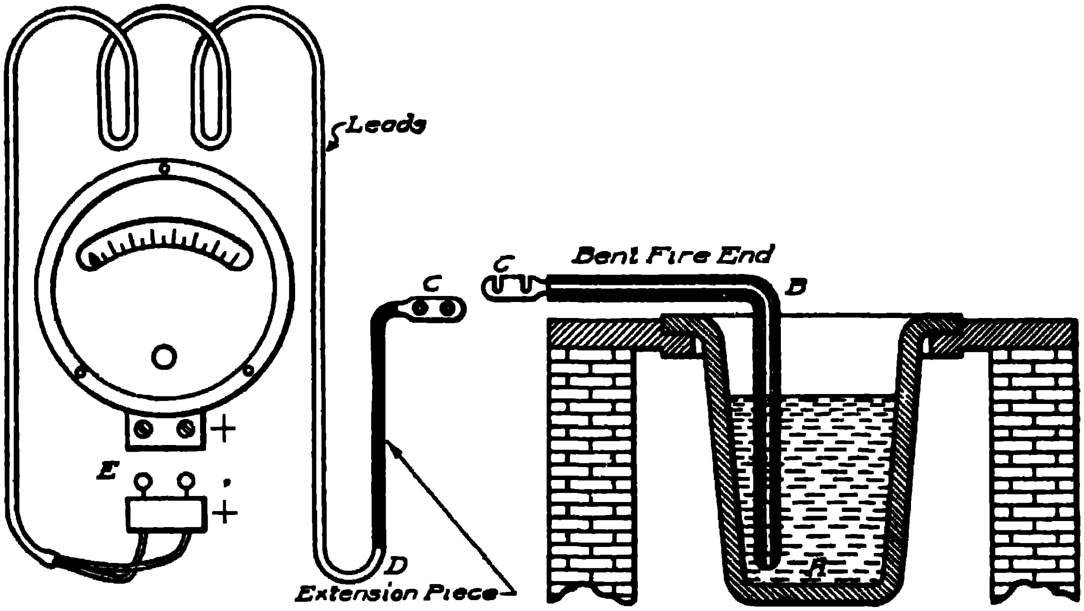

Fig. 10. An Electric Pyrometer Wired to a Salt (or Lead) Bath

Molten salt baths containing sodium cyanide, sodium chloride, calcium chloride, sodium carbonate, barium cyanide, potassium cyanide, and other substances are used in applying heat treatments, including hardening, tempering, annealing, normalizing, case-hardening, cyaniding, nitriding, etc. Molten salts transmit heat rapidly and uniformly to the steel or nonferrous products, and protect them during the heating period by coating the product immersed in the bath with a thin film of salt. This film adheres to the heated metal even after it is removed from the molten salt bath and is ready to be plunged into the quenching tank. Safety measures must be provided, however, to avoid the dangerous reactions that can occur in the mixing of certain salts. The fused salts must be protected from the harmful effects of moisture. When cyanide salts are used, care must be taken to protect the operator from poisonous fumes rising therefrom. Fig. 9 shows the molten salt bath equipment used in case hardening. Fig. 10 shows a diagrammatic layout of how an electric pyrometer is used with a salt or lead bath. It can be used to good advantage in forged-tool hardening. If a salt bath is used, it should be made up of such a composition as will be neutral to the metal that is to be heated in it. One of the chief advantages of the liquid bath for treating metals is that the gaseous atmosphere is eliminated. Also, with correct operation, there can be no overheating of the steel.

TABLE III. CHARACTERISTICS OF COMMON METALS WITH THEIR ANNEALING AND HOT-WORKING TEMPERATURES

Metal	Workability at Room Temperature	Lowest Recrystallization Temperature after Severe Cold Working, Deg. Fahr.	Usual Annealing Temperature Range after Cold Working, Deg. Fahr.	Usual Hot Working Temp. Range Deg. Fahr.
Aluminum	Very good	300	650	600–900
Brass	Very good	400	1000–1250	*1100–1650
Bronze	Fair	750	1000–1250	1100–1650
Copper	Very good	‡400	1000–1400	800–1900
Duralumin	Good	600	640–670	600–850
Gold	Excellent	390	500–1000	*........
Iron	Good	840	1100–1400	1500–2400
Lead	Excellent	Below room temp	Anneals itself	*... .. .
Monel Metal	Fair	800	1350–1450 in box	1600–2100
Nickel	Fair	1110	1100–1750	1600–2300
Steel, Structural	Fair	900	1100–1400	1500–2200
Steel, High Carbon	Poor	1000	1100–1400	1400–2000
Silver	Excellent	390	500–1000	*........
Tin	Excellent	Below room temp.	Anneals itself	*........
Tungsten	Poor	2190	2200–2500	1100–2900
Wrought Iron	Poor	900	†	1650–2450

*Usually worked at room temperature

†Wrought iron is not cold worked

‡Perfectly pure copper may recrystallize at temperatures as low as 212°F after severe cold working.

Table III lists some of the important characteristics of metals commonly used in processes described in this chapter.

REVIEW QUESTIONS

1. What is the purpose of heat treatment of forgings?
2. Describe the process of annealing steel forgings.
3. Describe the process of normalizing steel forgings.
4. Describe the process of hardening steel forgings.
5. Describe the process of tempering or drawing steel forgings.
6. Discuss briefly the formation of color oxides on the surfaces of heated steel.
7. Describe the process of induction hardening of steel forgings.
8. What is flame hardening?
9. What is cyaniding?
10. What is nitriding?
11. What is spheroidizing? Chapmanizing?
12. What is the purpose of heat treatment of nonferrous forgings? Name some of the methods
13. Describe the method of solution heat treatment of aluminum alloys.
14. Describe the method of precipitation hardening of aluminum alloys.
15. Name some of the heat-treating furnaces for steel.
16. Describe briefly the important features of electric furnaces for heating steel.
17. Describe the operation of a hydryzing furnace.
18. What are the advantages of immersion heating in liquid baths?
19. Describe the operation of oil baths.
20. Describe the operation of lead baths.
21. Describe the operation of salt baths.
22. Discuss the use of electric pyrometers.

CHAPTER XII

Inspection and Testing of Forgings

Purpose of Testing and Inspection. Inspection of forgings is a procedure that is necessary to insure the right quality of the product. The materials which go to make up various forgings are tested periodically in order to control the future quality of the finished product. Many defects may exist in the materials proper, before actual manufacturing has been undertaken. The inspection of semifinished, as well as finished products, is carried out in order to determine whether the quality of these products is in accordance with established standards and specifications. The American Society for Testing Materials, through various committees representing manufacturers, consumers, engineers, and other interested groups, has drawn up specifications for forgings. These are recognized as standards for the forging industry.

The specifications are fully described in the literature issued by the American Society for Testing Materials, and by various forging manufacturers. The use of these specifications is recommended wherever applicable. To enable the user to follow specifications pertinent to the type of forged product that he is interested in, a convenient classification has been arranged as follows: recommendations for conventional practice, and recommendations for unusual requirements or service. The type of steel is recommended for the particular forgings; not only the finished steel, but also the blooms, billets, and slabs for the forgings. The chemical compositions developed by different manufacturers of forgings are listed in the recommendations, to enable the user of forged products to select the most suitable material for his particular needs.

Methods of checking and testing the mechanical properties of forgings are recommended, such as tension tests of specimens of the material, tests of the yield point and yield strength of the material (to show resistance to deformation), impact tests (to show resistance to sudden blow and shock), fatigue tests, and other strength tests. Macro-etch testing (a visual examination of the surface of a sample after it has been suitably etched with some reagent) is applied to some steel products. Hydrostatic-pressure testing is applied to hollow or bored vessels, pipes, and other products, which are to be subjected to pressure in service. Usually, it is an internal-pressure test. Tests of hardening potential and other heat treatments are required in some cases. In some special cases, forgings are subjected to heat indication and dimensional stability tests. An illustrative example is the turbine rotor, which must remain straight and run true at the temperature of operation.

Common Defects in Forgings. Defects in forging materials are often responsible for poor-quality forged products. Therefore, a periodic check of the quality of the material which goes into the forging will insure a high-grade product that can be used successfully in actual service without resorting to costly replacements. The possibility of failures, when defective forgings are put to work in parts of fast-moving machines, constitutes a vital factor to be considered. To avoid failures, the most exacting care is exercised in the selection of the material, and in the manufacture of the forged part. To make sound forgings, both chemically and structurally, scientific knowledge of materials and high skill in the manufacture of the product are fully employed. Defects which may be detected during the forging operation, or discovered in the finished product, represent a definite loss. The seriousness of that loss depends upon the type and size of the forging—defection of a large forging is, naturally, a costly experience. Frequently, defects are not discovered until all machining and heat treating are completed. Such an occurrence creates a serious and costly problem. If it occurs often, a thorough investigation of the material and manufacturing method should be made.

Defects most commonly found in metals that have been subjected to more or less plastic shaping may be classified as follows:

1. Defects resulting from the melting practice, such as the presence of dirt, slag, or impurities separated from the iron in the melting process; and blowholes, which are caused by liberation of gases while the ingot solidifies from the molten state.

2. Ingot defects, such as pipes (openings in the center of the ingot), cracks, scabs, or bad surface and segregation. Segregation is a condition produced by uneven concentration of elements contained in the metal.

3. Defects resulting from improper forging, such as seams, cracks, laps, etc. These are definite openings, separations, and fractures.

4. Defects resulting from improper heating and cooling of the forging, such as burnt metal, decarburized steel, and flakes. Decarburized steel is caused by contact of the heated steel with the atmosphere. The carbon is removed from the surface of the solid steel by this oxidizing action.

It is often difficult to detect the defects in forgings unless they are on the surface and of such size as to be readily seen with the naked eye. Defects beneath a layer of scale or deep within the forging are much more difficult to detect. Various testing methods have been devised to aid in the inspection and checking of metal parts, for the purpose of insuring against serious defects.

After the forging operation is completed, there is a possibility of formation of flakes and other internal ruptures owing to the increase of mass and hardening potential of the steel. Various methods of conditioning and heat treatment may be applied to the forging before it is allowed to cool to room temperature in order to avoid the above undesirable conditions. Controlled cooling or heat treatment may also be required on semiformed products, such as blanks, blooms, and billets, which are reheated and further reduced in size in the final forging operations. The type of treatment and conditioning depend upon the composition of the metal, size of the work, and degree of complexity of the forged product.

The hot working of metal during the process of making a forgeable steel refines and compacts the grain structure. Thus, a metal of greater grain uniformity, and one relatively free of hidden defects is obtained. The continued hot working of metal in closed impression dies results in forged parts which are free of concealed defects.

Inspecting and Selecting Forging Materials. The first step in the production of forgings is a careful examination of the forging stock, in order to insure quality. In the case of most steel forgings, carefully produced high-grade steel is needed. This steel, as previously stated, is usually rolled in the steel mill to the proper size from high-grade billets. While the steel is being produced in the mill it is periodically checked against prescribed chemical and physical specifications. These specifications are determined by the actual service the finished forging will have to perform.

Inspection of the forging metal, particularly steel, should reveal an excellent surface on the stock, and an inner structure that is clean and sound. This inspection includes chemical analysis, surface inspection, hot-acid etch tests, and forging tests. The results of these tests are positive and determine whether or not the steel is to be accepted for forging.

Obviously, selection of materials is a prerequisite of prime importance to the design and fabrication of products in general. However, to choose the material best suited to meet anticipated service requirements is very often quite a problem. Compounding the problem is the fact that modern metallurgy has developed a wide selection of metals in which various physical properties are often duplicated. Sufficient information is at the disposal of the product design engineer in various publications sponsored by sources interested either in the fabrication of metal or the manufacture of production tools. This informative data is not only a reference, but also a guide in selecting materials and processes which, according to test indications, will meet various types of service stresses to the best advantage

Data on forging materials include information on the physical properties, hardening qualities, fatigue strength, impact characteristics, and similar features determined by the testing laboratory. Tests may be made either on prepared laboratory specimens of the metals under consideration, or on full-size components of existing comparable parts. A metallurgical analysis of the material consists of a visual examination of a conveniently prepared section of the metal. This examination may be either macroscopic or microscopic, and is usually employed for checking purposes in securing metal-quality control in production. The macroscopic examination is made either with the naked eye or under low magnification. The microscopic examination employs the use of microscopes and other optical instruments. In the macroscoping examination, the specimen is studied at a magnification of 25 times or less. The surface of the section being examined is suitably etched, depending upon the condition which is to be illustrated. For example, fracture grain size, segregation of impurities, and type of structure are conditions subject to inspection. Microscopic examination is usually made at a comparatively higher magnification. The aims of the study are: evaluation of the microstructure, measurement of grain size, and identification of impurities, together with a determination of the amount, size, and shape of the impure particles.

Surface Inspection of Forged Parts. The surfaces of forgings are inspected visually for cracks, seams, laps, burnt spots, excessive scale, and rust. Forging laps are, more or less, an obvious defect, and can often be found by visual examination. Usually, the cause of forging laps is easily determined. Frequently, laps are caused by improperly designed or mismatched dies, which prevent the proper flow of the metal during forging. Fig. 1 shows the defect, called forging lap, in a section of a forged wood-bit.

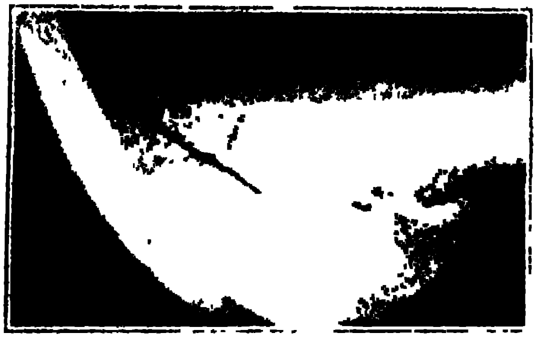
Fig. 1. Forging Lap in a Wood-Bit

The lap shown in Fig. 1 extends from one end of the piece to the other. Improperly designed dies and deficient forging technique caused this pronounced defect.

Frequently, a test by fracture or cutting of metal parts will expose defects. The line of rupture usually travels through the defective areas, resulting in their discovery. Sectioning of metal parts by shearing or machine cutting may expose defects that are below the surface of the metal. Fig. 2 shows a longitudinal section of a cold-drawn rod with a badly ruptured core. This type of defect may be caused by excessive cold working or by the combination of a segregated weak core and cold work. This kind of defect has been observed in sections ranging from fine needle wire to inch bars—material that has been subjected to cold drawing.

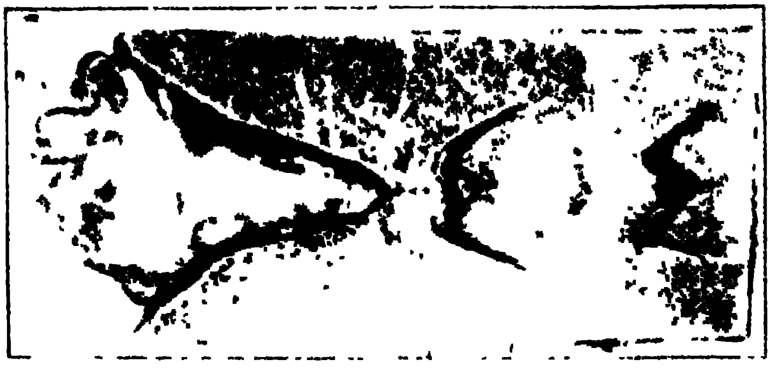
Fig 2. Section of Cold-Drawn Rod Showing Internal Defects

Hot-Acid Etch Test for Steel Forgings. One of the most inexpensive and common tests for defects in steel forgings is that of hot-acid etching. Hot-acid etch tests are of two classes: (*a*) for surface defects, such as seams, laps, and slivers; and (*b*) for internal defects, such as porosity, pipe, and segregation.

The etching test for surface defects consists of immersing short pieces of steel bars or billets in hot diluted sulphuric acid for 15 minutes. The acid removes the mill scale. The mill scale forms on the surface of the heated steel as a result of its contact with the oxygen of the atmosphere. The test for internal defects consists of sawing and polishing samples from the bars under investigation, and then immersing them for 30 minutes in a solution of one part commercial hydrochloric acid and one part water heated to 160° F. The effect of the hot-acid etching of the tested metal is the revealing of its structural characteristics, i.e., the grain structure and its arrangement.

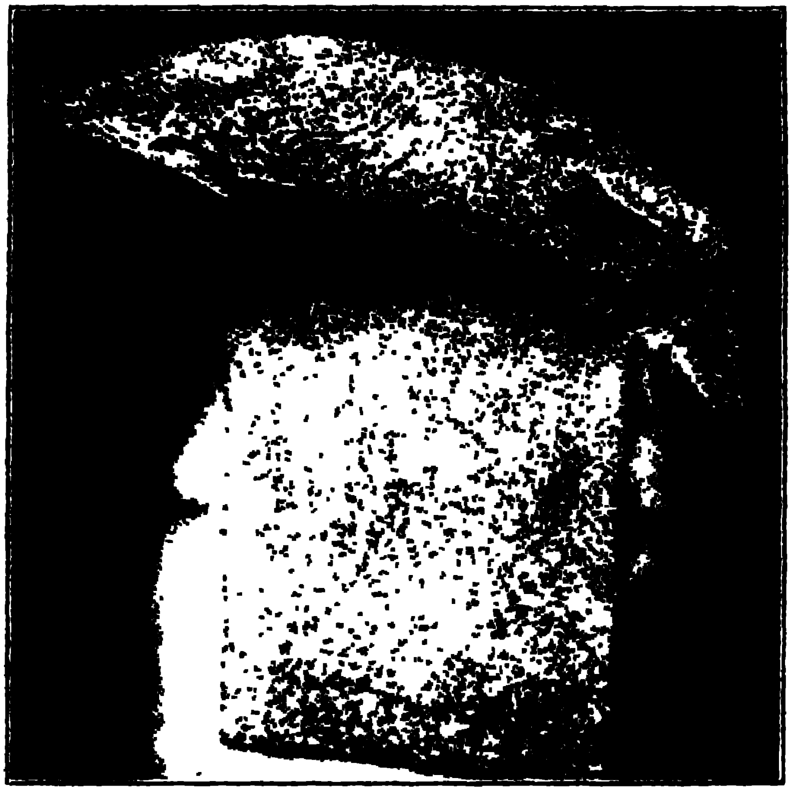

Fig. 3. Hot-Acid-Etched Section of Bolt Showing Failure That Started during Cold Upsetting

Fig. 3 shows a hot-acid-etched bolt revealing failure that started during cold upsetting. In this etched section of the cold-upset bolt, failure started from internal rupture in the bolt's head. This rupture was caused by cold working beyond the limit of steel's ductility.

Examination with Microscope. The polished and etched sections of forgings are frequently examined with the aid of a microscope. Defects that are not apparent to the naked eye can be detected by the microscope. Fig. 4 shows a microscopic view revealing slag streaks, formed from impurities, in the longitudinal section of a steel forged spindle. The presence of this slag indicates improper melting practice for this type of steel. Owing to this defect the spindle life in actual service was considerably shortened—a very unsatisfactory happening for this type of product. The slag shown in the figure may result in cracks, hair lines (thin, minute cracks), and marked directional properties of the grain flow in the forging.

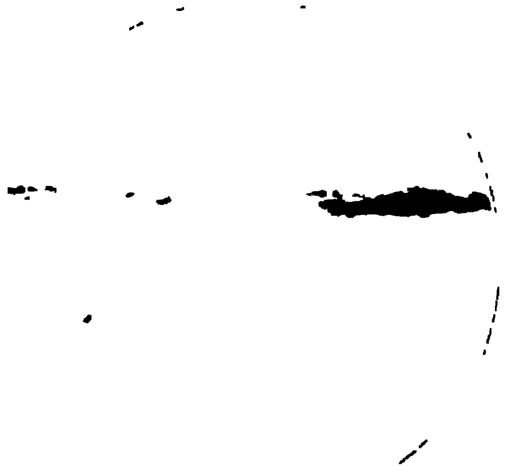

Fig. 4. Longitudinal Section of a Forged Spindle Showing Slag—Magnified 100 Times

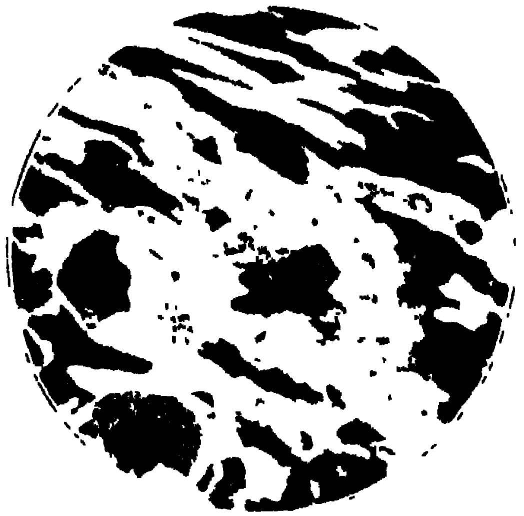

Fig. 5. Distortion of Structure on Roughly Machined Surface—Magnified 100 Times

Fig. 5 shows the effect of rough machining a forged part. The marked distortion of the structure near the surface of the forging may be a source of warping or even cracking during the subsequent heat-treating operations.

Nondestructive Testing. Nondestructive testing is an excellent method used to achieve and control quality in metal parts. X-rays may be shot through a piece of metal. By passing between the atoms composing the metal, the rays often indicate conditions existing beneath the surface. Metal sections over 4 inches thick are penetrated by X-rays which use voltages up to 300,000 volts, and which disclose the presence of unsoundness, such as fractures and other similar defects.

A nondestructive test, known as *Magnaflux inspection*, is also being used for the detection of surface defects in steel—defects such as cracks, seams, and laps. In this test, the steel is first magnetized. Then, a fine iron dust is applied to the surface. Any discontinuity of the metal on or near the surface affects the iron dust and leaves a clue to the hidden defect.

The Magnaflux method offers many advantages and some limitations in the detection of defects on forged products. The advantages include greater sensitivity in showing up surface defects, some of which may be so small that they might be missed by other methods. This process of inspection is very rapid, and the defect indications are easy to find. The defects revealed by this method include superficial ones, and also ones immediately below the surface—defects which are not visible by other methods of inspection. This method is limited to ferromagnetic metals or alloys. The location of all subsurface defects is not always revealed by this method, however. Much depends upon the character and depth of the defects.

Fine ferromagnetic powder is applied to the forging, either wet or dry, depending upon the method used, and a pattern is formed at points of flux leakage. This pattern indicates the location and general character of the defects. The most important phase in the inspection procedure is the magnetization of the part, for the magnetic field must be created at right angles to the defect. If a seam is parallel to the magnetic field, no indication will appear. Irregular-shaped pieces must be magnetized in several directions, with the part being demagnetized between each operation. Fig. 6 shows a Magnaflux tester in the process of checking aircraft forgings. This is only one of a number of tests for quality of vital aircraft forgings. The Magnaflux Corporation of Chicago manufactures an assortment of testing equipment for checking various products, particularly forgings. The reader is advised to obtain the valuable information pertaining to this checking equipment directly from the above firm. The information is contained in pamphlets published by the firm.

Assurance of Forging Quality by Over-All Control of Operations. Quality in forgings is obtained only by exacting control over all of the operations or phases of steel manufacture, from the mining of the ore to the finish heat treating and ground forging. Quality, in order to be controlled, must be positively defined by exacting specifications. Specifications formerly read, "steel for carriage tires," or "blacksmith's bar forging steel," or "shafting steel," or "steel for plow shares," or "railroad iron," etc. Modern specifications should include the chemical analysis, desired hardness, tensile strength, ductility, resistance to shock, etc. In fact, any and all information concerning the service which the steel will be expected to render should be included in the specifications.

Forgings, manufactured in modern plants where mass-production conditions prevail, may be purchased now at much lower cost than when the forging industry was just beginning to adopt volume-production techniques. Today, forgings are of much better quality than ever before. Great skill is now exercised in general metal production and, as a result, forged products are excellent in quality and diversified in form.

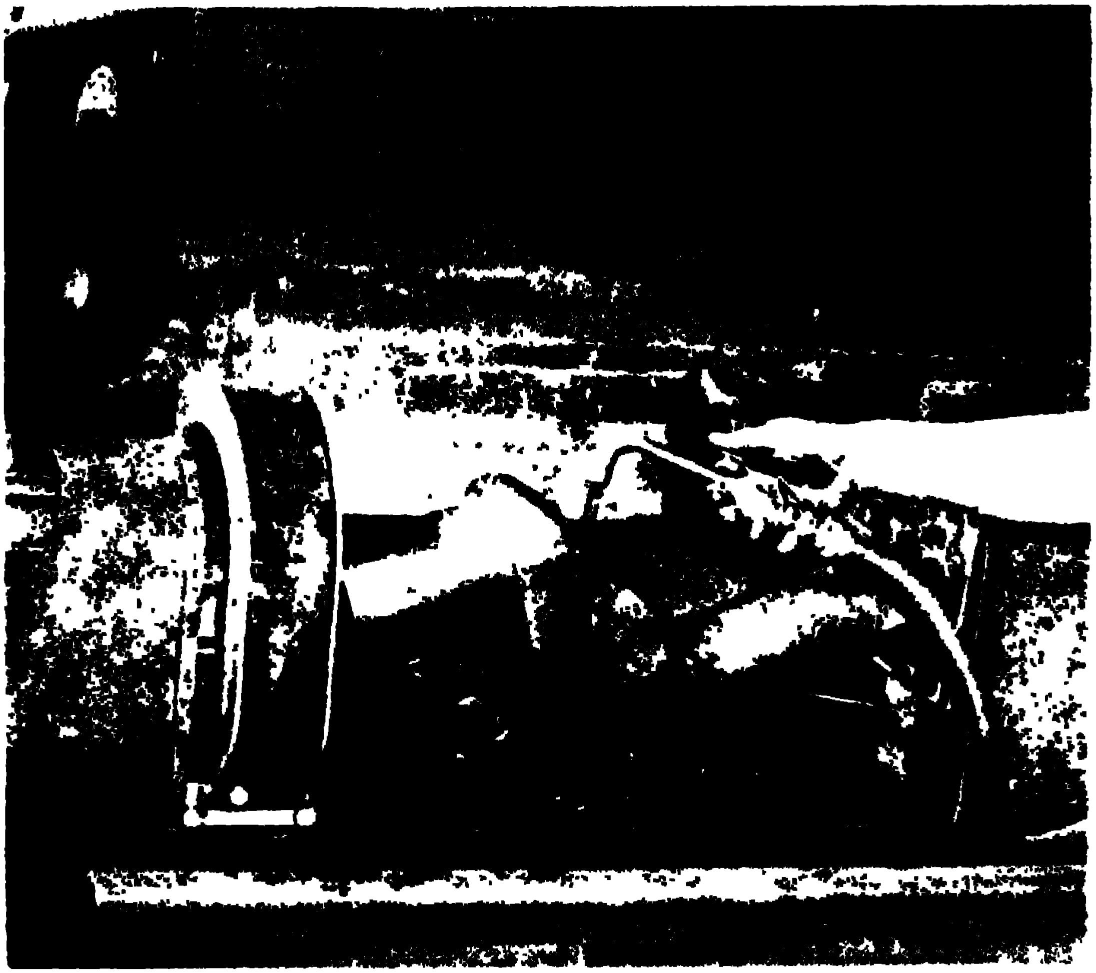

Fig. 6. Magnaflux Tester for Checking Aircraft Forgings

Courtesy of The Steel Improvement and Forge Company Cleveland, Ohio

Identification of Steel. There are many varieties of iron alloys which are used in the manufacture of numerous products. Some practical methods, aside from comprehensive physical and chemical analyses, are desirable in order to identify the particular metal under consideration. There is a possibility in any plant for various grades of steel to get mixed. Even though a bar of steel is marked by paint or some other means of identification when purchased, this marking may soon wear off or probably be cut off, leaving a bar with no identifying sign on it to tell the next user what grade of steel it is. In the production of tools, it is essential for the toolmaker to select the grade of tool steel that will be suitable for the particular product to be made. A simple method to determine whether the right material is used is very helpful in this, as well as in many other cases. There are several practical methods used for identifying iron alloys. Two of them are: the spark test, and the fracture test.

The *spark test* is an inexpensive test which takes little time and can be applied without destruction of the metal. It consists of placing the iron or steel in contact with a rotating emery wheel, and then observing the sparking of the lighted particles which are thrown off from the surface of the wheel. The sparking of these particles will often occur before they fall on the floor. The small particles, which are broken off the metal when the latter comes in contact with the rotating grinding wheel, become heated to a red or yellow heat owing to friction. When these small heated particles are hurled through the air, they come in contact with oxygen, which causes them to become oxidized or burn. If an element (such as carbon) which burns easily is present, rapid combustion occurs and sparking will be seen.

In the case of wrought iron or very low-carbon steel being ground on the emery wheel, no sparking or very little of it will take place, because of the low carbon content in the metal. However, lighted streamers will shoot from the surface of the wheel toward the floor, and appear dull in color near the wheel. These streamers will become very bright and glow at a point rather far from the wheel, after which they will turn dull again and fall on the floor.

When a piece of high-carbon steel is brought in contact with the surface of a rotating grinding wheel, a bright sparking occurs immediately (there is no sparking around the circumference of the wheel if low-carbon steel is ground). The spark of the high-carbon steel will die out before reaching the floor. In the case of a very high carbon content in the steel, none of the particles that come off the wheel will reach the floor—all of them apparently are consumed by the air. The reason for this is that high-carbon steel burns more easily than low-carbon steel. This indication also explains why much precaution is taken in heating the metal when high-carbon steel is being forged. Care in such instances prevents burning of the metal.

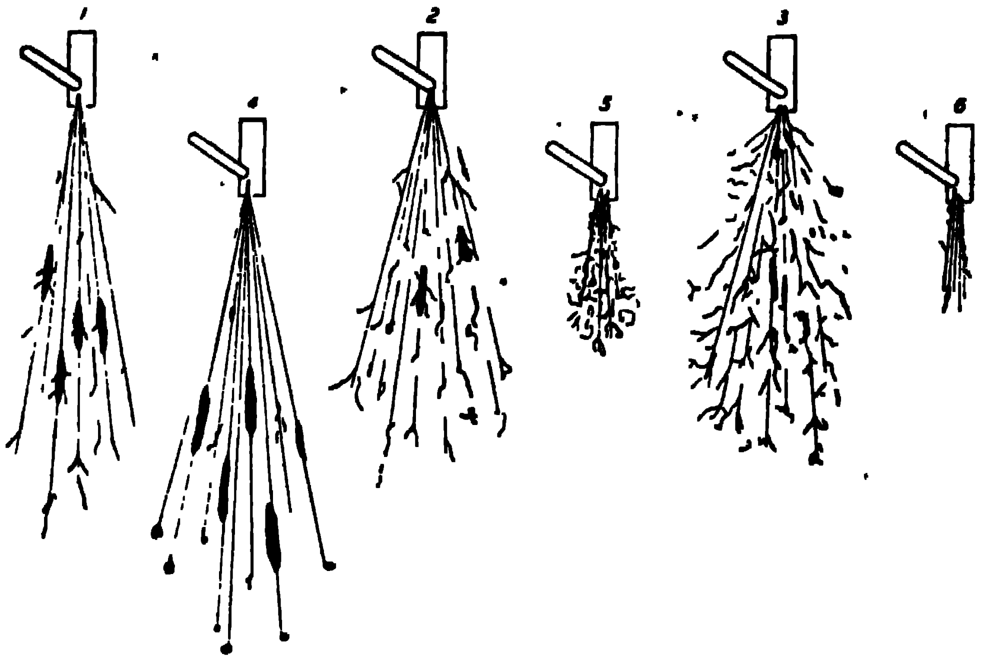

Fig. 7. Characteristic Sparks of Different Irons and Steels as Thrown Off by a Grinding Wheel: *1*, Low Carbon Steel, *2*, Medium Carbon Steel, *3*, High Carbon Steel; *4*, Wrought Iron; *5*, White Cast Iron; *6*, Gray Cast Iron

Courtesy of American Society for Metals

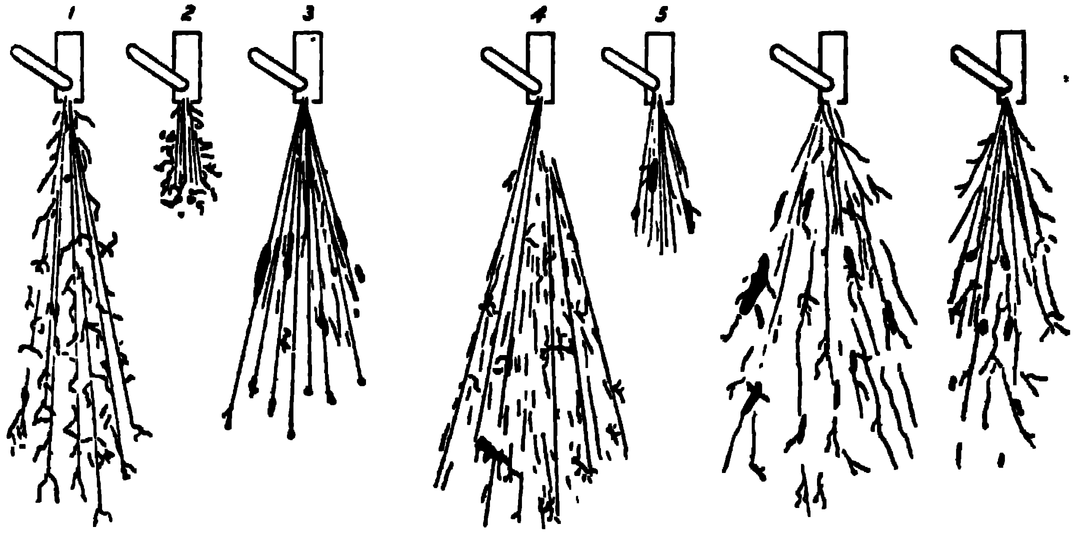

Fig. 8. Characteristic Sparks of Different Alloy Steels as Thrown Off by a Grinding Wheel: *1*, Tool Steel; 2, Punch and Die Steel; *3*, Heavy-Duty Chisel Steel; *4*, Hot Work Die Steel; *5*, Stainless Steel; *6*, Nonshrinking Tap and Threading Die Steel; 7, Magnet Steel

Courtesy of American Society for Metals

Steels of different analyses will give different spark appearances upon coming in contact with the grinding wheel. Forging workers should become familiar with the characteristic sparks of various steel samples of known analyses, in order to become adept at identifying unknown pieces of stock by the spark method. After an operator acquires sufficient practice, he can use the spark test to ascertain the amount of decarburization that has occurred during the forging operations. Another useful application of the test is determination of the depth of case hardening of carburized pieces. Figs. 7 and 8 show a series of characteristic sparks of different iron alloys as thrown off by a grinding wheel. A detailed description of the spark characteristics of different irons, steels, and alloys is given in Table IV. Additional information regarding spark tests of steels and alloys may be obtained from the *Metals Handbook,* 1948 edition, published by the American Society for Metals.

The *fracture test* affords much valuable information concerning the character of a steel. If a piece of steel is fractured by some convenient means (such as nicking the metal with a saw or chisel, clamping one end of the piece between the jaws of a vise, and then striking the free end with a hammer), an inspector will be afforded indications as to whether or not the steel is soft and ductile, soft and brittle, or hard and brittle. Examination of the fracture will also reveal whether the carbon content of the steel specimen is high or low. The examination of a fractured iron casting will reveal whether it is gray, white, or malleable cast iron.

Low-carbon steel will not fracture easy. It will first bend and be quite tough. The fracture will appear to be of a light gray color, and frequently the grain size can be noted if the fracture has not been distorted badly. If heated to a bright red heat (about 1500° F.) and quenched in water, the piece of metal will not exhibit much change in properties, such as hardness, upon fracturing.

High-carbon steel, because of its being more brittle than low-carbon steel, will stand less bending and will fracture easier. The fracture will also glisten more, and the grain size will be revealed with more clarity. If heated to a red heat (approximately 1450° F.) and quenched in water, the high-carbon specimen will undergo marked changes in properties. Such steel becomes very hard and brittle, and the fracture will be very fine and silky in appearance after the heating treatment.

Gray cast iron is not forgeable. However, it must be identified

TABLE IV. SPARK CHARACTERISTICS OF DIFFERENT IRONS, STEELS, AND ALLOYS

Metal and Composition	Spark Characteristics
Carbon Steel 0.05 to 0.10 Carbon	Streamers thrown from the wheel are light straw in color. They follow a straight line and become broader and more luminous some distance from the wheel. Streamers are caused by small particles of metal becoming heated and thrown off the surface of the wheel. The streamers burst into a characteristic spark, but this is not very noticeable. No sparking or feathering around the periphery of the wheel.
Carbon Steel 0.20% Carbon	Some more carbon sparking or bursting of the streamers than with the 0.05 per cent carbon steel. The luminous part of the streamer forks are caused by the bursting. No feathering
Carbon Steel 0.30% Carbon	More sparking or bursting, causing a forking of the streamers. No feathering.
Carbon Steel 0.40% Carbon	Increasing of the explosions or bursting, with greater forking and a brighter golden color to the streamers. Slight feathering around periphery of the grinding wheel.
Carbon Steel 0.60% Carbon	A greater number of explosions, and color is a copper yellow. The higher the carbon content, the nearer to the wheel becomes the forking. Feathering around the wheel.
Carbon Steel 0.80% Carbon	An increasing number of bursts or explosions and less distance of travel of streamers. Feathering.
Carbon Steel 0.90% Carbon	Bursting is very numerous, marked forking occurring, often sub-dividing. Feathering. The color is a golden white.
Carbon Steel 1.00 to 1.40% Carbon	With increasing amounts of carbon the streamers become less apparent because sparking or bursting takes place very near to the surface of the grinding wheel. This bursting and forking is very numerous. Much shorter length to the streamers. The color becomes reddish. Marked feathering occurs.
Gray Cast Iron	Very thin streamers and short in length. Some sparking as with carbon steel, but not very noticeable. The color is a brick red, and the streamers tend to curl up on the end. No feathering.

TABLE IV. SPARK CHARACTERISTICS OF DIFFERENT IRONS, STEELS, AND ALLOYS—*Continued*

Metal and Composition	Spark Characteristics
White Cast Iron	Similar to high carbon steel only much thinner streamers and less sparking. The streamers near wheel are a brick red. Slight feathering.
High Silicon Cast Iron	Practically no streamers and only a red flare near wheel.
Nichrome Metal Nickel and Chromium	Very thin streamers, reddish in color and very short. Oxygen has very little effect on this material.
Malleable Cast Iron	Streamers quite wide and short, some sparking or bursting taking place, causing a forking. Color is an orange red.
Wrought Iron	Very similar to low carbon steel. Long yellow streamers becoming luminous near the end, with practically no carbon sparking, causing slight forking. No feathering.
Heavy Duty Chisel Steel 0.40% Carbon 1.7% Tungsten 1.0% Chromium	Similar to wrought iron but much shorter. Few explosions near the surface of wheel. Red streamers and no feathering.
Magnet Steel 0.65% Carbon 5.5% Tungsten	Red streamers with a forking of yellow streaks. This forking begins near wheel and continues the length of streamers. A few carbon sparks causes more forking to occur.
Drop Forge and Die Blocks 0.55% Carbon 0.6% Chromium 1.5% Nickel	Same characteristic spark as carbon steel of same carbon content.
Hot Work Die Steel 0.65% Carbon 13.5% Tungsten 3.75% Chromium 1.0% Vanadium	Short length of streamers with very fine explosions. The color is reddish and streamers are very faint.
High Speed Tool Steel High Chromium High Tungsten	This is somewhat like the hot work die steel and has a reddish color streamer which follows a broken line, with very slight explosions, showing just a trace of the carbon spark. No feathering.

from white cast iron or malleable cast iron. Gray cast iron fractures easily, and it is soft and brittle. The fracture is coarse-grained, and its color is dark gray.

White cast iron is very hard and brittle, and will fracture very easily. A fracture of this iron will reveal the grain size. Its color is white. White cast iron is not forgeable. It is difficult to machine, except by grinding.

Malleable cast iron is not forgeable, and cannot be worked cold. However, it does not fracture easily, because it is much tougher and more ductile than either gray cast iron or white cast iron. A fracture of malleable cast iron appears to be in the form of a case and core. The case is at the edge of the fracture, and has the appearance of low-carbon steel. The core is at the interior of the fracture, and is similar to gray cast iron, except it is of a darker color.

Wrought iron is very difficult to fracture because of its toughness. If heated and then quenched in a cold liquid, wrought iron shows no change in its properties. The fracture appears darker than low-carbon steel, and it seems fibrous. This latter appearance is due to the streaks of slag that may be observed on the surface after cleaning off the scale.

In conclusion, it may be stated that the spark and fracture tests are very simple and rapid and are, therefore, useful in practical applications. However, microscopic analysis, notwithstanding the fact that the equipment is expensive and that the procedure requires considerable time, is quite essential in numerous cases. It gives good evidence of the composition of a material, and also furnishes reliable indications of the properties that can be expected of the material.

REVIEW QUESTIONS

1. What is the purpose of testing and inspecting forgings?
2. Name some of the methods of checking and testing the mechanical properties of forgings.
3. Name some of the common defects in forgings.
4. How may concealed defects in fabricated parts be avoided?
5. What is the first step in the successful production of high-quality forgings?
6. Discuss the importance of selecting proper materials for forged products.
7. What important properties should be possessed by forging materials?
8. Describe surface inspection of forged parts.
9. Describe the hot-acid-etch test for steel forgings.

10. How can the microscope aid in the examination of forgings?

11. Name some of the nondestructive testing methods used in the examination of forgings.

12. Describe the Magnaflux method as used in the detection of defects on forged products.

13. What are the prerequisites for the assurance of forging quality?

14. Name some of the methods used in identifying steel.

15. Describe briefly the spark test as used in identifying the kind of steel being tested.

16. Describe briefly the fracture test as used in testing steel.

17. What are the advantages of the spark and fracture tests?

CHAPTER XIII

Forging Dies and Tools

Importance of Proper Design of Forging Dies and Tools. Forging dies and tools play a vital role in the successful accomplishment attained in various forging methods. Forging is not ordinary hot working of metals, where billets and bars or other simple elementary shapes are produced; it is working to impart, by pressure, definite required shapes to metal parts according to strict specifications.

In the production of steel billets and bars, the force exerted by the constantly rotating rolls, between which the metal is passed, operates in the nature of a drawing process to refine the metal and develop its structure in the direction of the rolling. When a forging is being produced in a die, the hot working of the metal consists of a hammering or kneading action which not only shapes the billet or bar, but at the same time further refines the metal. Such action results in a dense and tough fiber structure throughout the forged product. Thus, a billet or bar of metal, particularly steel, is transformed into an essential component of an operating mechanism, such as an automobile, airplane, locomotive, or any other mechanism used in various applications.

As previously stated, all hot-forging operations may be accomplished by either employing plain (flat) dies or closed-impression dies. Plain or flat dies used in smith forging are shown in Fig. 1. These dies have no impressions to shape the hot plastic metal to exact form and dimensions required, but provide a certain amount of development in metal quality. The forced metal flows sideways between the dies, and the shaping is carried out by manipulating the metal for repeated blows from the hammer.

Closed-impression dies, shown extensively in Chapters V and VI, have impressions sunk in the faces of the dies for the purpose of forming the metal by pressure to specified shape and dimensions. This method of forging also controls the direction and concentration of the inherent fiber-flow structure of the metal. Thus a substantial improvement in the properties and quality of the metal is obtained, making it suitable to meet specific conditions in actual service. Forgings of various shapes and sizes, ranging in weight from a few ounces to several hundred pounds, may be produced in closed-impression dies. Flat dies used in smith forging may be employed in closed-impression dies. Flat dies may be employed for forgings ranging in weight from a fraction of a pound to over 200 tons. Carefully designed and constructed closed-impression dies and tools are very important factors in attaining the highest development of metal quality and accurate shaping of the required part, throughout the sequence of forging operations.

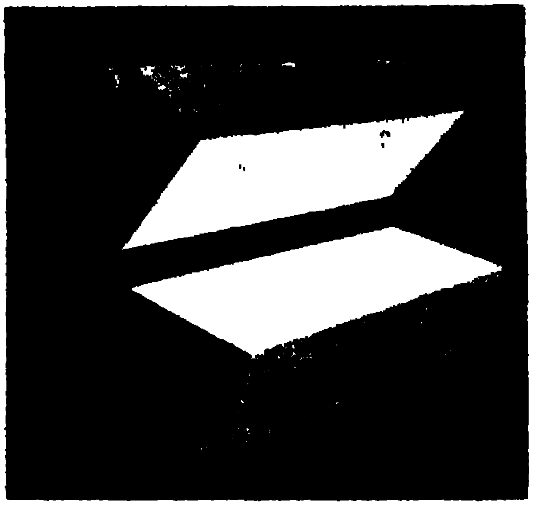

Fig. 1. Set of Plain or Flat Dies

Courtesy of Drop Forging Association, Cleveland, Ohio

Procedure in Making Closed-Impression Dies. Closed-impression forging dies must be designed to shape the part and, at the same time, develop the metal structure to provide maximum strength and dependability. This twofold objective requires planning by the designer of impressions that not only will impart the necessary geometrical form to the metal, but also will promote alignment of the inherent fiber structure of the steel, and produce further refinement of the grain. Expertly designed die impressions will insure that the flow lines and grain density of the metal will be properly positioned to offer maximum resistance at points of greatest stress. Development and controlled directioning of these strength-giving factors are usually accomplished in the preliminary steps of edging, fullering, and blocking, in order that the final shape may be attained without breaking the continuity of the fiber structure.[1]

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[1] Discussion in this paragraph is based upon information contained in *Metal*

One set of dies, as stated in Chapters V and VI, may be sufficient for the preliminary and finishing forging operations when producing small and medium-size parts. However, in the case of larger or more complicated forgings, several sets of dies may be required, and the preliminary and finishing operations may call for one or several pieces of equipment for completion of all the forging steps. Large and irregular forgings may be conveniently rough-formed by smith forging, leaving the final blocking and finishing steps to the closed-impression dies. Upon completion of the die design, the required impressions are sunk in the heat-treated special-steel die blocks. A thorough knowledge of the behavior of metals while they are being worked in the plastic state plus skill born of experience are both requisite to successfully design and make closed-impression dies.

The following illustrations demonstrate the essential steps in making a set of closed-impression dies for drop-forging a steel connecting rod. The preparation of closed-impression dies for machine forging and press forging requires essentially similar procedures.

Impressions sunk in die blocks outline the size and shape of a forging, and provide the means for forming a forging to tolerances that reduce subsequent machining and finishing costs. Rough die blocks are obtained from die-block makers, who are specialists in the field. The rough blocks are delivered to the die-block storage room of the forging plant. Die blocks are usually made from high-alloy steel, and range in weight from a few pounds to several tons each. In the die-block storage room, the die blocks are grouped to permit enough space between them so that overhead lifting devices can be used to convey them to the tool room. There, the sinking of impressions of a required forging is carried out by skilled craftsmen. This involves many machine and hand operations.

The preliminary machining of the die blocks consists of drilling holes in the sides of the blocks opposite each other. Handling bars may be inserted in these holes. This facilitates ease in lifting and handling heavy die blocks. Fig. 2 shows the operation of drilling holes in the die blocks.

The next step consists of moving the rough die blocks to the planer, where the shanks for the attachment of these die blocks in the forging hammer are machined. The size of the shank depends upon the standard size of the shanks established in a particular forge

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Quality, published by the Drop Forging Association, Cleveland, Ohio, 1949. Adapted with permission.

shop for the size of forging hammer required. This operation is illustrated in Fig. 3. While the die blocks are in the planer, another operation follows after the shanks have been cut. This operation consists of turning the die blocks over on the bed of the planer, and planing enough metal from the face of each die block to obtain clean and sound metal for the impressions which are to be sunk. Then, as a next step, two edges of each block are planed inward from the side, and downward from the face, at exact right angles with each other, and at exact right angles with the face of the die block. All dimensions may now be taken, in laying out the die impressions, from these two matched edges and the planed face, as shown in Fig. 4. The matched edges also serve another important purpose—they facilitate exact alignment of the die blocks when placed in the forging hammer.

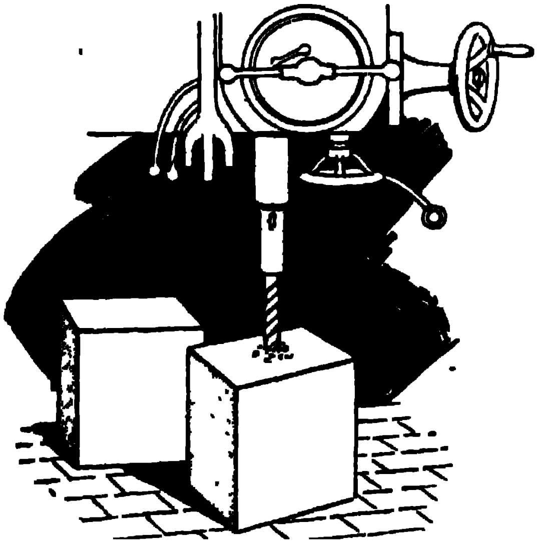

Fig. 2. Drilling Handling Holes in Die Blocks

Courtesy of Drop Forging Association, Cleveland, Ohio

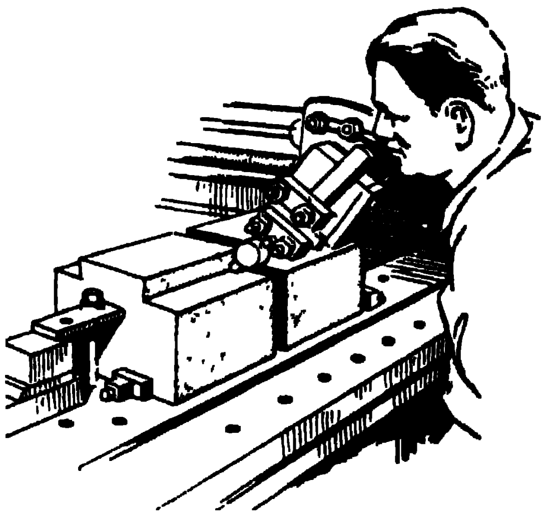

Fig. 3. Cutting Shanks in Die Blocks on Planer

Courtesy of Drop Forging Association, Cleveland, Ohio

Sinking the Finishing Impressions. This operation consists of first laying out the template or outline of the finishing impression, which is to be sunk in the die block, on its machined face. In the absence of a template, the layout is made from the forging or die drawing. A color background is provided on the face of the die block to secure a convenient surface for the marking of the outline of the forging. This may be accomplished by coating the face of the block with copper sulphate or a similar-purpose solution. The location of the finishing impression in each die block (for shaping a forging to exact contour) is usually arranged in such a way that the weight center of the forged product is at the geometric center of the ram, i.e., midway from side to side and from front to rear of the ram. Fig. 5 shows this operation.

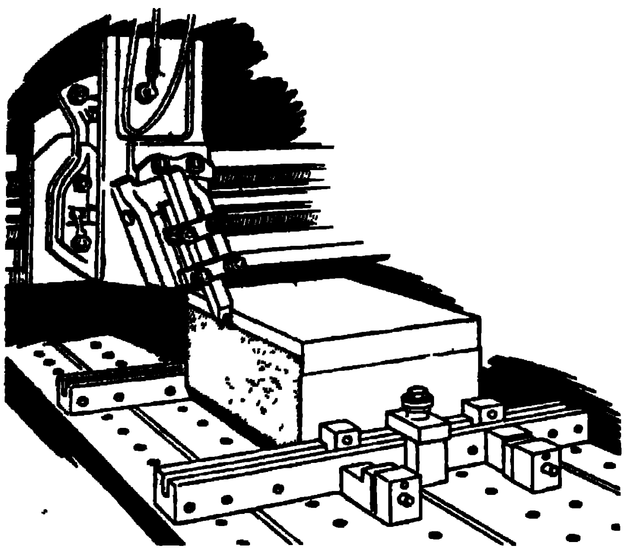

Fig. 4. Planing Faces of Die Blocks
Courtesy of Drop Forging Association, Cleveland, Ohio

Fig. 6 shows the operation of sinking the finishing impression into the face of the die block. This die-sinking operation is done with the most modern machine tools specially designed for this purpose. The accuracy of the finishing impression is very important, since it shapes the forged product to its final width, depth, and thickness. Modern machines sink the finishing impression within a few thousandths of an inch of the correct dimensions. The method of sinking a finishing impression varies; it depends upon how complex the design of the forging is.

The machine work on the finishing impressions in the die blocks is followed by hand work on the bench—work such as scraping, filing, grinding, and polishing the cavities. Fig. 7 shows this operation of hand working the finishing impression on the bench. The finishing impressions must be true for every dimension. They must be lapped and polished free of all tool marks and sharp corners, so that the impressions will allow the metal to move with least resistance in filling the cavities of the dies. Impressions thus completed produce forgings to close tolerances with a minimum of abrasive wear.

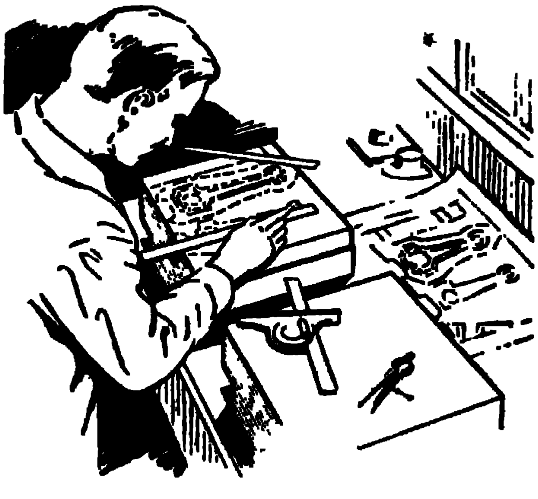

Fig. 5. Outlining Finishing Impression on Machined Face of Die Block
Courtesy of Drop Forging Association, Cleveland, Ohio

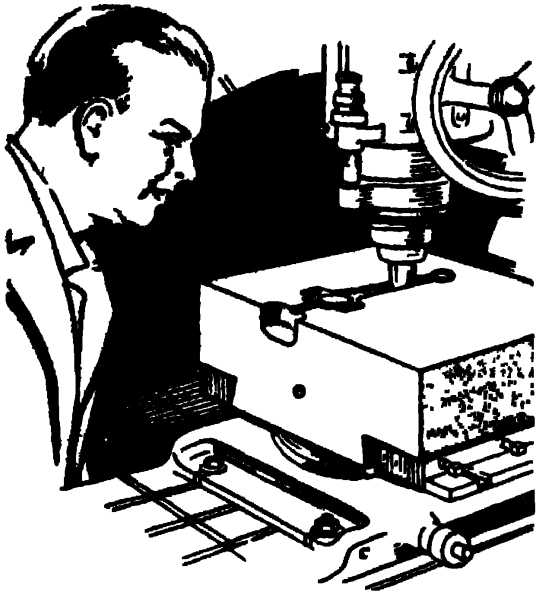

Fig. 6. Sinking Finishing Impression into Face of Die Block

Courtesy of Drop Forging Association, Cleveland, Ohio

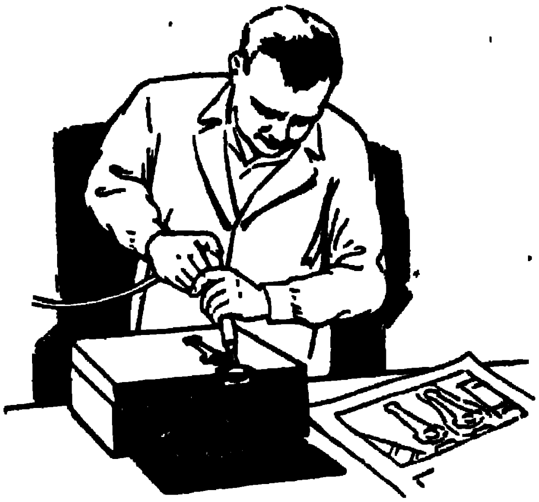

Fig. 7. Scraping, Filing, Grinding, and Polishing the Finishing Cavities

Courtesy of Drop Forging Association, Cleveland, Ohio

The Preparation of the Lead Cast. Upon completion of the bench work on the finishing impressions, the upper and lower dies are clamped together in exact alignment, using the matched edges as guides. Molten die metal, such as lead or some other suitable composition, is poured in the die cavity through a *sprue* (a trough or "gate" that is machined into each die block from its outer edge and extends to the cavity of the finishing impressions). A lead cast or "proof" of the finishing impressions in the dies is thus obtained. This lead cast is a preview facsimile of the forging which, upon completion of all die impressions, will be formed in these dies as required. The operation of obtaining a lead cast of a finishing impression is demonstrated in the drawing shown in Fig. 8.

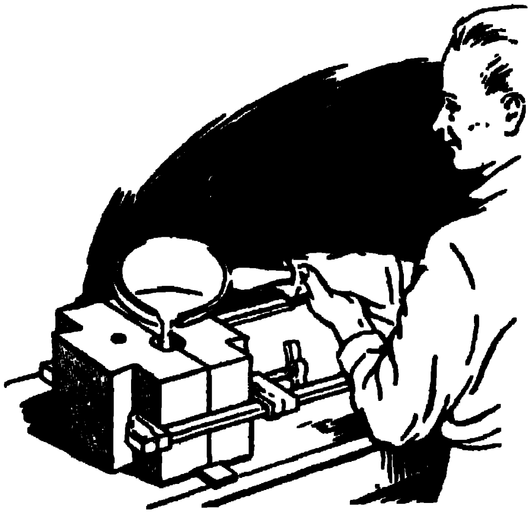

Fig. 8. Obtaining Lead Cast of Finishing Impression

Courtesy of Drop Forging Association, Cleveland, Ohio

The lead cast is now carefully checked for dimensional accuracy by the die maker, as well as by the engineer or other person charged with responsibility for maintaining the required quality of the forged product. The lead cast may also be checked by the producer and the user of the forgings, before final approval for release for production is obtained. In the event that some dimensions are found to be incorrect, the finishing impressions are further worked until they check in conformity with the correct specifications. The lead cast is also used to check the estimated weight of the forging by multiplying the weight of the lead cast by a factor depending, in part, upon the weights of various materials that can be used to make the forged product.

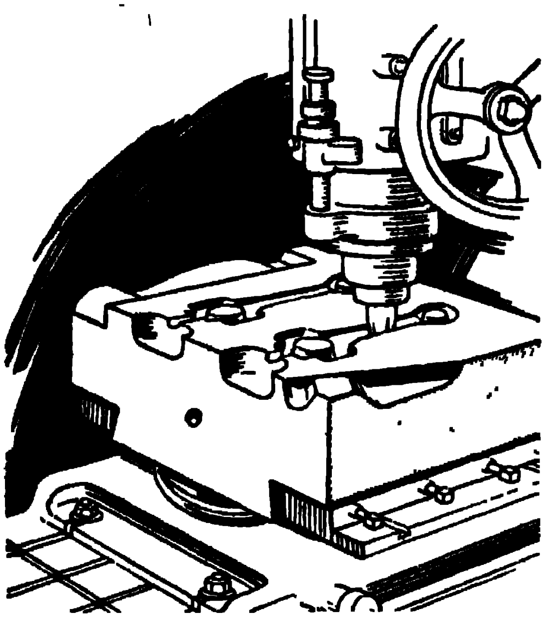

Fig. 9. Sinking Preliminary Impressions in Die Blocks

Courtesy of Drop Forging Association, Cleveland, Ohio

Sinking the Preliminary Impressions. When once the lead cast is certified as being correct in all specifications (such certification is evidence that sinking of the *finishing impressions* have been successfully accomplished), the sinking of impressions other than finishing impressions is begun. These other impressions are provided in many sets of dies for such preliminary stages of hot-working the metal as fullering, edging, and blocking, i.e., stages that take the metal from its original state, as a bar or billet, through successive forging operations up to but not including work in the finishing impressions. Depending upon the type of product, impressions are sunk in the die blocks for one or more other preliminary operations. The preliminary operations may, however, be sunk in a separate set of die blocks, rather than in the set wherein the finishing impressions are sunk. This is especially true when it is necessary to employ two or more sets of die blocks to form a forging. Fig. 9 shows the operation of sinking impressions for preliminary working in the die blocks.

The extent of additional die machining, after the correct lead cast is obtained, depends upon the number of preliminary operations required to form the forging under consideration. This latter circumstance varies with the complexity of the shape of the forging. The arrangement or sequence of the preliminary forging operations also depends upon the shape and size of the product, and the technique adapted in the particular forge shop.

When a forging is finally formed in the finishing impression, there is a possibility that some metal will be in excess of that required to completely fill the cavities of the finishing impression. As stated before, this excess of metal, or flash, may begin to form at the blocking operation. However, most of it will develop at the finishing impression, where the full impact of the hammer blows is utilized to the utmost. To contain this excess of metal, it is essential to provide a *gutter* (groove) for it around the entire shape of the finishing impression. When this gutter is machined in, the necessary machine work required for a given set of forging dies is completed. Calculation of the gutter dimensions must provide for an adequate area to receive the flash metal, which is subsequently trimmed from the finished forging by a set of trimmer dies mounted in a mechanical press. Fig. 10 shows the operation of machining the flash gutter around the finishing impression in the die.

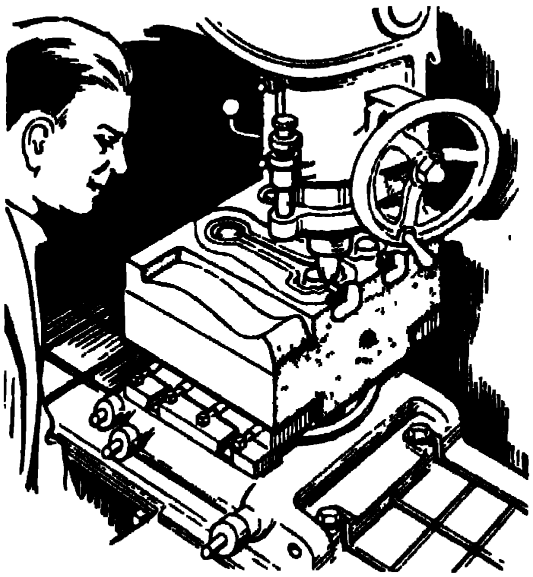

Fig. 10. Machining Flash Gutter around Finishing Impression

Courtesy of Drop Forging Association, Cleveland, Ohio

The machined dies are now returned to the bench. If any additional hand tooling or grinding or polishing is necessary, the die sinker immediately fulfills these final requirements. Furthermore, he carefully examines all surfaces of the sunk impressions to make sure that no imperfect portions are present—imperfect areas that could ultimately retard the flow of the plastic metal under pressure, or hinder in any way the rapid hot working of each section of the metal that enhances the quality of the product to the maximum extent. Fig. 11 shows these final operations on the bench.

Fig. 12 shows the operation of drilling dowel holes into the shank of each die block. These holes are provided to facilitate locating the dies properly in the forging hammer. Upon completion of this operation, the dies are completely machined. However, the drilling of these locating holes may be done at an earlier stage, usually after the face of each die block is machined.

A final inspection completes the sequence of operations before the dies are ready to be mounted in the forging press. The impressions for the preliminary operations are thoroughly checked to assure proper hot working of the metal in these stages. Proper hot working, in turn, assures the development of metal quality, which is so vital to successful performance by the forged product. No further heat treatment of the dies is required, since the original die blocks furnished to the die-sinking shop were previously heat treated. Fig. 13 shows the final inspection of the completed die blocks.

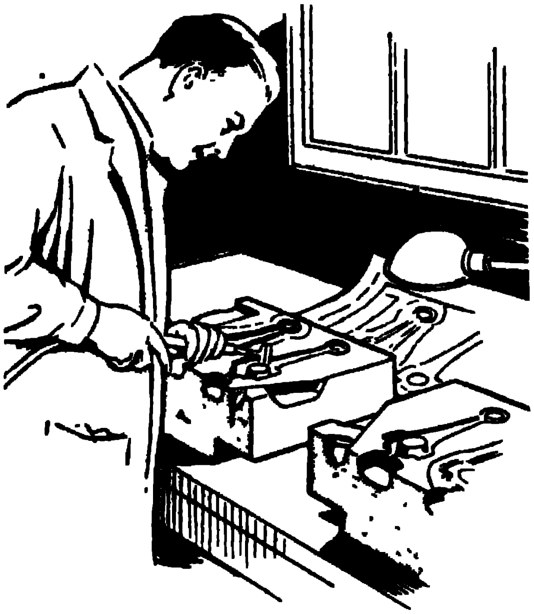

Fig. 11. Final Grinding and Polishing of Die Impressions

Courtesy of Drop Forging Association, Cleveland, Ohio

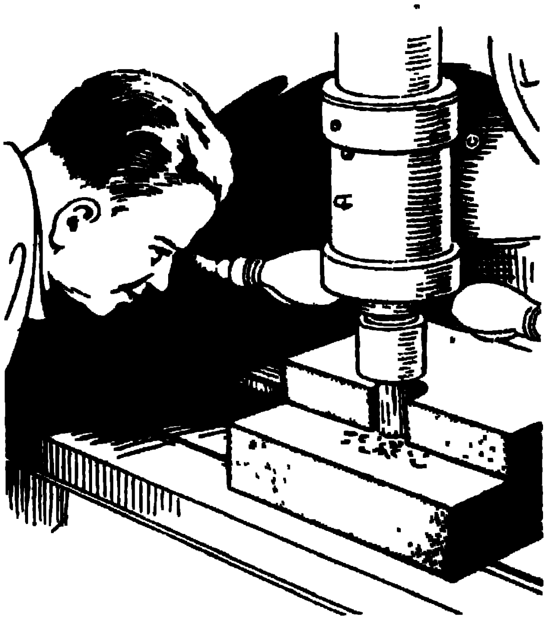

Fig. 12. Milling Dowel Holes into Die Shanks

Courtesy of Drop Forging Association, Cleveland, Ohio

Fig. 14 is an illustration of a set of die blocks used for forming a connecting rod. Various elements of this pair of die blocks are as follows: *1*, holes for handling bars; *2*, shanks; *3*, matched sides or edges from which all dimensions are taken for sinking impressions in faces of die blocks; *4*, faces of die blocks; *5*, dowel slot or hole (not visible, cut crosswise of shank); *6*, edging impression; 7, fullering impression; *8*, blocking impression; *9*, finishing impression; *10*, gutter for flash; *11*, sprue; *12*, gate or depression for tonghold. Such a set of die blocks is capable of producing thousands of connecting-rod forgings of identical size and shape, and of uniform metal quality.

The completed dies are now placed in a board or steam drop-forging hammer, with the top die in exact alignment with the bottom die. This alignment is of utmost importance, since it assures minimum wear and strain on the dies, as well as on the hammer, during the forging operation.

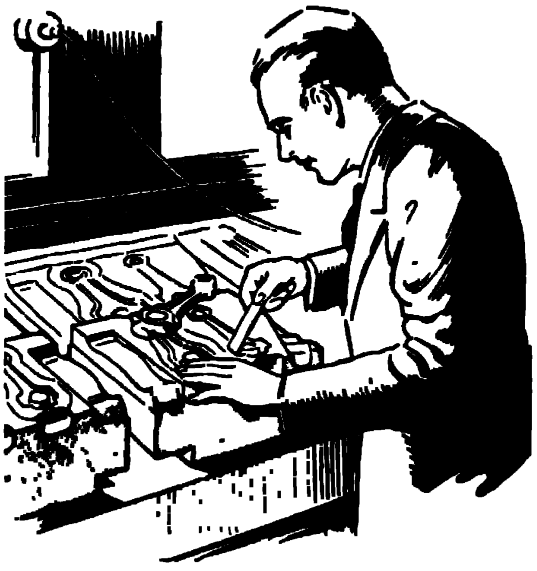

Fig. 13. Final Inspection of Dies

Courtesy of Drop Forging Association, Cleveland, Ohio

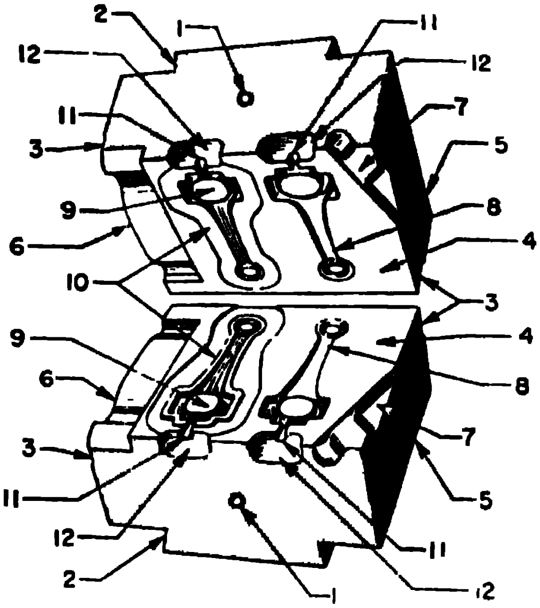

Fig 14. Set of Die Blocks for Forging Connecting Rods

Courtesy of Drop Forging Association, Cleveland, Ohio

Closed-Impression Dies for Nonferrous Forgings. Forgings of nonferrous metals, such as copper, copper-base alloys with their numerous compositions of brass and bronze, and the light alloys of aluminum and magnesium, are made with closed-impression dies by drop forging, machine forging, and press forging. These various metals require different forging temperatures and certain modifications in forging techniques, as compared with the methods used in making steel forgings. Structural characteristics of nonferrous forgings, as developed by closed-impression dies, are similar to those found in steel forgings. The following illustrations show typical designs of closed-impression dies for forging an aluminum-alloy housing for aircraft. A large number of aircraft parts are forgings made of strong and light aluminum alloys. Fig. 15 shows two views of the finished aluminum forging that constitutes the aircraft housing —the product for which a sequence of forging operations is outlined, and for which appropriate dies are designed. The finished housing is approximately 14¼ inches in diameter and 5½ inches in height.

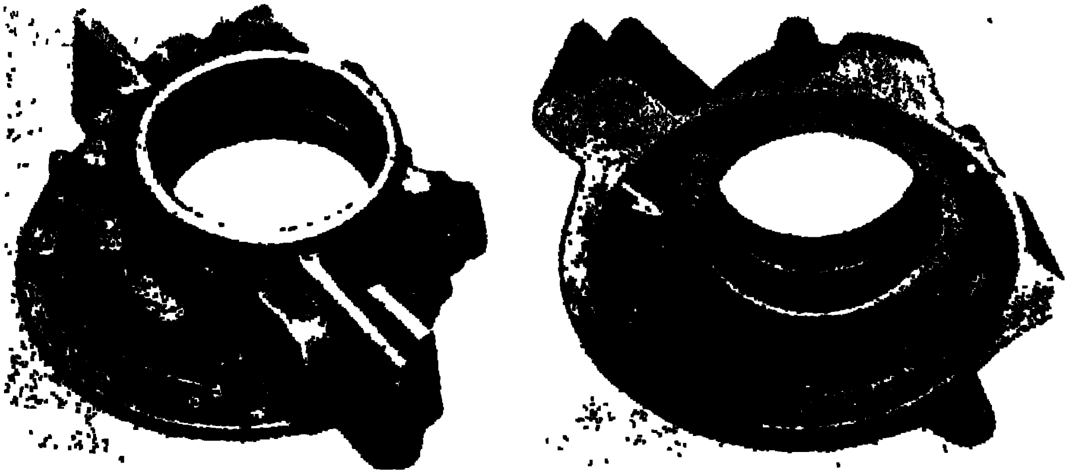

Fig. 15. Two Views of Finished Aluminum Housing Forging

Courtesy of Drop Forging Association, Cleveland, Ohio

Three separate sets of closed-impression dies are required for forging this part in a drop-forging hammer. The stock for this forg-

Fig. 16. Aluminum Bar Stock for Housing Forging

Courtesy of Drop Forging Association, Cleveland, Ohio

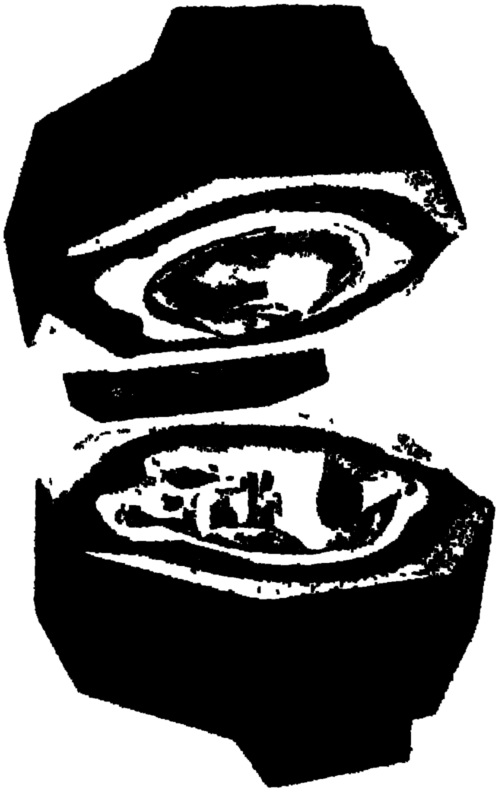

Fig. 17. First Blocking Dies for Forging Aluminum Housing

Courtesy of Drop Forging Association, Cleveland, Ohio

ing is cut from an aluminum bar to length sufficient for making one piece, as shown in Fig. 16. After heating to the proper forging temperature, the stock is first upset and flattened in flat dies.

Preliminary forming and distribution of the metal takes place in the first blocking dies, shown in Fig. 17. Definite shape of the part is attained in the second blocking dies, shown in Fig. 18, and finishing dies, shown in Fig. 19, complete the part.

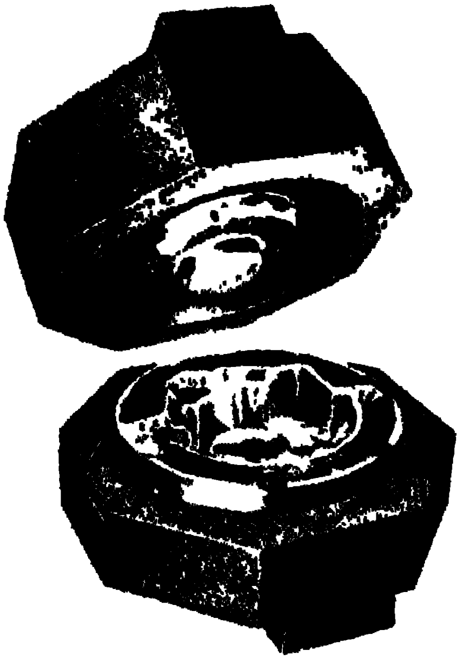

Fig. 18. Second Blocking Dies for Forging Aluminum Housing

Courtesy of Drop Forging Association, Cleveland, Ohio

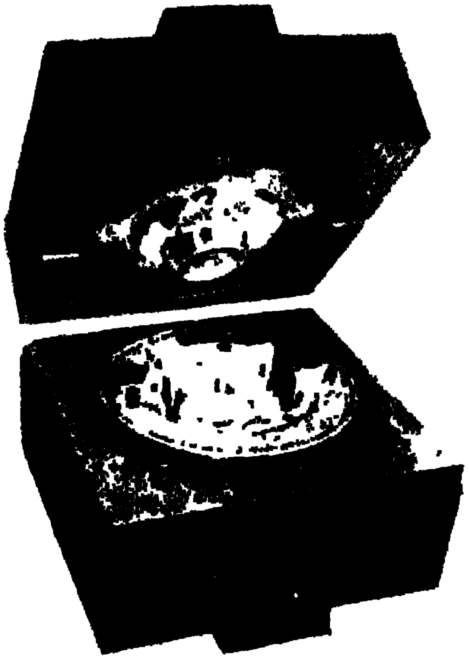

Fig. 19 Finishing Dies for Forging Aluminum Housing

of Drop [illegible] *Association, Clevela*[illegible]

The first blocking operation imparts a rough outline of the shape, as shown in Fig. 20, and distributes the metal properly for filling the more intricate pattern of the die cavities in later forming operations. Larger fillets help the metal flow at this stage, in order that continuity of the flow lines of the metal will not be interrupted in the final shaping. Definite shape of the part, as shown in Fig. 21, is attained in a second blocking operation in which the various bosses and projections are formed. Directioning and positioning of the fiber structure is completed at this stage. Referring back to Fig. 15, the finished forging may be seen after the flash has been trimmed away, and the large hole punched in the trimming operation. Forging blows struck while the metal is in the finishing set of dies impart the accurate final shape to close dimensional tolerances.

Tools and Dies for Machine or Upset Forging. The tools and dies used in a typical machine or upset forging operation are illustrated in Figs. 6 and 7, Chapter VIII, of this text. The tools shown in these figures were designed for production of a cluster gear in the forging machine or upsetter. Thorough knowledge of this type of forging, together with tooling experience, is essential in planning the sequence of the forming operations. In producing the cluster gear, a heated bar of steel is upset, in order to increase its diameter and shorten the original multiple length. In the final operation, the original multiple length is shortened to conform to the shape of the forging desired.

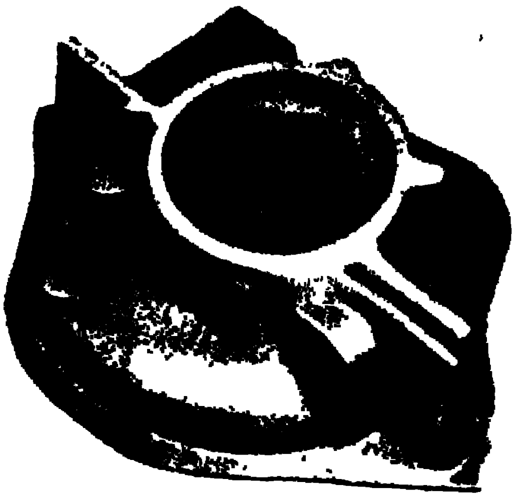

Fig. 20. Result of First Blocking Operation

Courtesy of Drop Forging Association, Cleveland, Ohio

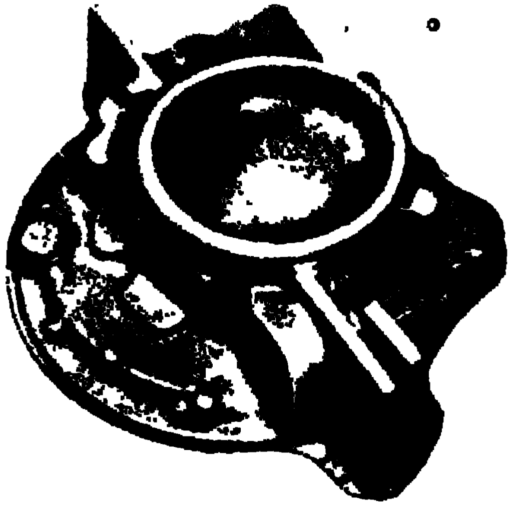

Fig. 21 Result of Second Blocking Operation

Courtesy of Drop Forging Association, Cleveland, Ohio

The tools and dies for upsetting may be designed for operations other than the conventional simple gripping and heading operations, since the transverse action of the moving die and the longitudinal action of the heading tool may be utilized for forging in both directions, either simultaneously or successively. As stated previously, the die motion, in addition to gripping, may be exploited for operations such as swaging, bending, shearing, punching, and trimming. At the same time, the heading tools used for upsetting may also be employed for punching, extrusion, slotting, trimming, bending, internal displacement, and other operations required to form the part according to specifications.

Tools and Dies for High-Speed Press Forging. The tools and dies used in this method of forging, together with some typical examples of products forged by this method, are illustrated in Figs. 10, 11, and 16, Chapter VII, of this text. Mechanical and hydraulic forging presses are used. The mechanical press is the unit most widely used. High-speed press forging employs the fast squeeze-pressure method for the production of forgings of steel, aluminum, copper, brass, manganese, and other alloys. Closed-impression dies with the necessary number of steps are designed for the proper forging of products of accurate dimensions and correct contours. Knowledge of process and experience in tooling dictate the best planning of the sequence of operations for obtaining a forged product in accordance with specifications. Properly designed dies and tools will result in a product requiring the least amount of machining and finishing operations, thus lowering production costs and saving material.

Tools for Extrusion of Nonferrous Tubes. The Revere Copper and Brass Corporation of New York are extruding their condenser tubes from suitable copper-base alloys in the following manner.

Solid cylindrical castings are used in this process instead of tubular castings, because the former are decidedly less liable to internal casting defects. These solid castings are cut into short billets measuring about 10 inches in length and 7 inches in diameter. After sawing, and prior to extrusion, each cut surface is carefully inspected for possible flaws and casting defects. In a solid cylindrical billet, internal casting defects, such as porosity, tend, if present, to concentrate in the center of the casting.

In the extrusion process, the first operation consists of pushing out a central plug of metal from the billet. Should the casting contain minor internal defects not detectable by visual inspection of the cut surfaces, the removal of this center often eliminates such imperfections. A 1,650-ton hydraulic press extrudes the tube from the billet, leaving behind a skin of metal in the form of a shell. All subsurface imperfections or inclusions that may have been present in the original casting are retained in this shell.

Fig. 22 (pp. 238 and 239) shows various steps in the process of extruding a tube, and the necessary tools for the successful accomplishment of the process. *A* illustrates how the billet is placed in a stock holder designed to contain it. In *B*, the billet is held in place by a ram, while a mandrel forces out the center portion of billet, which may contain casting defects. *C* shows the ram advancing and forcing the metal in billet to flow between the mandrel and die. The

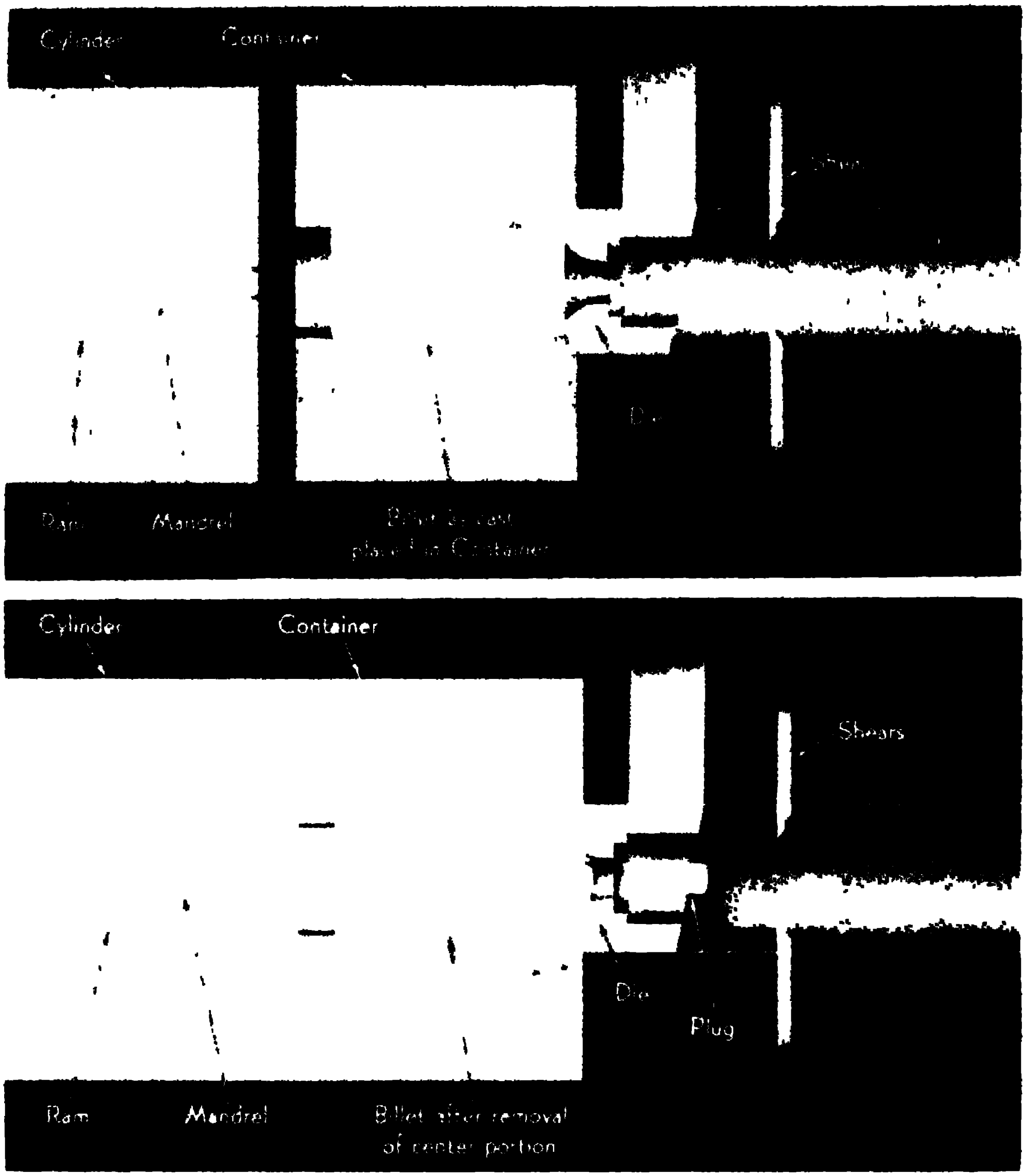

Fig. 22. Tube Extrusion—Steps *A* (*upper*) and *B* (*lower*)

Courtesy of Revere Copper and Brass Incorporated, New York, N.Y.

rough surface skin of the billet is not pushed out and remains in container. In *D*, the extrusion is completed. The remaining short butt end of the billet is sheared off from the extruded tube.[2]

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[2] Discussion under the heading "Tools for the Extrusion of Nonferrous Tubes" is adapted from matter contained in *Technical Information on Revere Copper and Copper Alloys*, published by Revere Copper and Brass, Incorporated, New York, 4th ed., May, 1947.

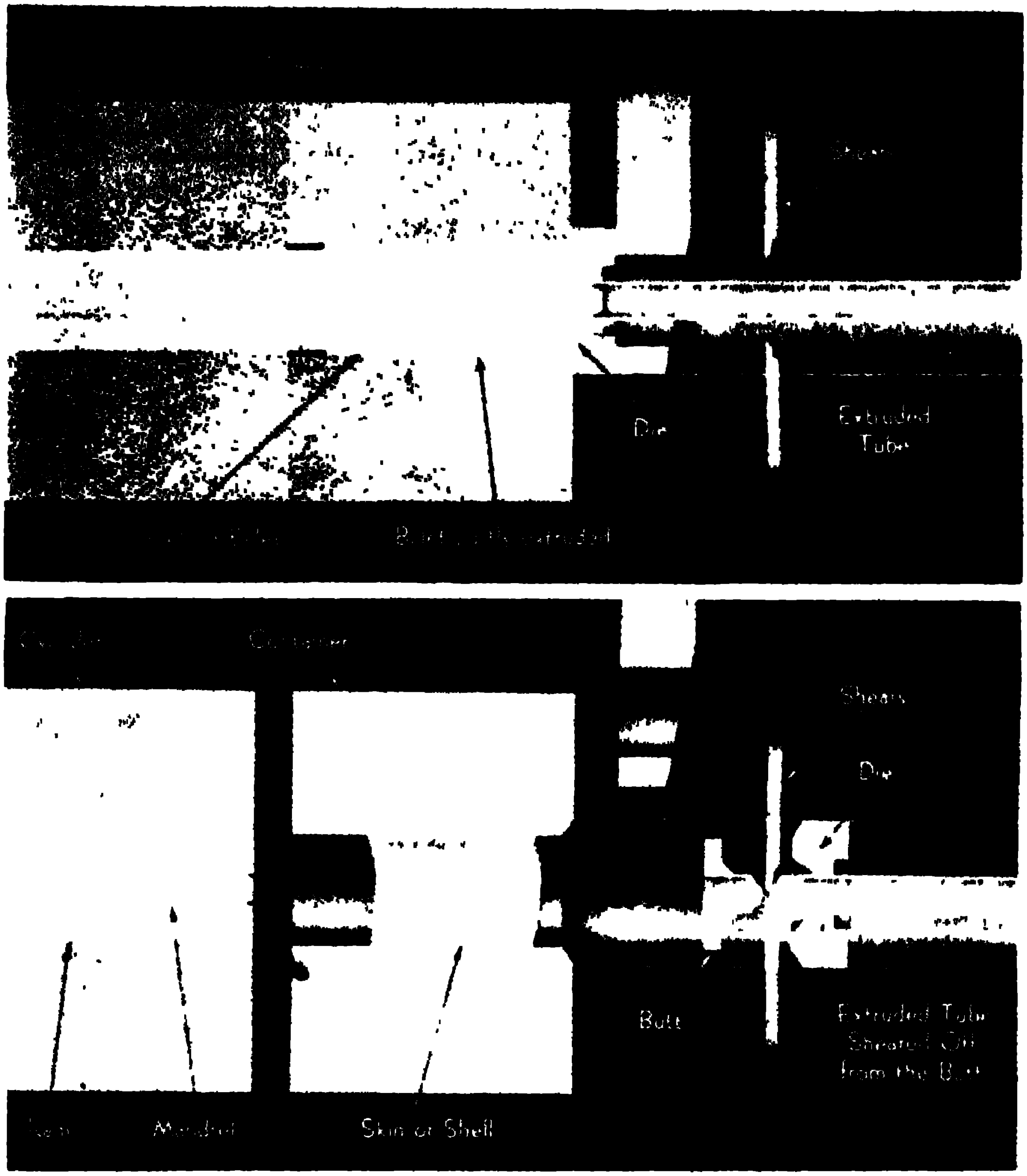

Fig. 22. Tube Extrusion—*Continued*—Steps *C* (*upper*) and *D* (*lower*)
Courtesy of Revere Copper and Brass Incorporated, New York, N Y

REVIEW QUESTIONS

1. Discuss the importance of proper design of forging dies and tools.
2. Describe briefly the procedure in making closed-impression dies.
3. Name some of the steels used in making closed-impression dies.
4. Describe briefly the preliminary machining operations performed in the making of die blocks (drilling handling holes, planing shanks, planing faces, and planing matched edges.
5. Describe the operation of sinking the finishing impressions in closed-impression die blocks.

6. Discuss the preparation of the lead cast.

7. Describe the purpose and procedure of checking the lead cast.

8. State what bearing the lead cast has on the sinking of preliminary impressions in the die blocks.

9. How much additional die machining may be necessary after the correct lead cast is obtained?

10. What are the finishing operations after the dies are machined?

11. What is the extent of final inspection before the dies are mounted in the forging press?

12. Name the elements of the die blocks, as shown in Fig. 14 of this chapter.

13. Discuss the use of closed-impression dies in connection with the production of nonferrous forgings.

14. Discuss tools and dies for machine or upset forging.

15. Describe the tools and dies for high-speed press forging.

16. Describe the tools for extrusion of nonferrous tubes.

17. Describe the method of extrusion of nonferrous tubes.

18. Describe the sequence of operations of the extrusion process, and name the necessary tools used in extruding a tube as shown in Fig. 22 of this chapter.

CHAPTER XIV

Product Design for Forging

Considerations in Designing Forged Parts and Dies. In order to obtain the maximum value from a forged product, the designer and the producer are governed by certain special requirements. Of course, the basic shape and size of the part to be forged are determined in the same manner as any other element of the part is. The physical limitations of the unit or assembly in which the component part must fit and service requirements determine specifications Finally, when selecting the forging method for producing the part under consideration to a specific shape and size, the design engineer should utilize to best advantage the inherent strength and stamina offered by forged metal. He should also bear in mind that the chosen design ought to favor the easiest possible production as a forged part.

The designer of a forged part is expected to have a working knowledge of the basic factors which affect forging operations, in order to incorporate the favorable qualities of a forging into the mechanical design of the part. The designer or forging engineer should exercise influence not only in the early stages of design, but also during all production operations through to the finished product. The specialized knowledge of design and production that designers and engineers possess make it possible to attain, in the forged parts, the utmost in physical properties of the metal. This objective can be gained without disregarding economy, both in the cost of the forging and in such subsequent processing operations as machining, heat treating, and assembling.

As stated in previous chapters of this text, forgings may be produced in a wide variety of sizes and shapes. Dies are employed for production of forgings in quantity. Alloy-steel dies are machined to form the necessary die impressions. Competent die designers arrange a division of the required impression between the top and bottom dies as equally as possible. This last is done to facilitate a proper and complete distribution of the metal for correct concentration of the inherent grain flow and fiber structure. The separating or parting line of the upper and lower dies is arranged to be in one plane as nearly as possible, so that excess metal, or flash, can be trimmed away with comparative ease. Of course, some difficult designs and shapes do not permit a parting line that is located more or less in one plane. In such a case, the forging dies are parted in two or even more planes, care being taken in the special design of the forging dies. These are so-called *locked dies.* They entail complicated layout and die-sinking operations. The die-parting line must be in more than one plane, in order to shape the part and permit a proper kneading of the metal. The latter insures desirable positioning of the grain flow and fiber structure in the finished forging. Finishing operations on the die impressions are then performed by hand.

Recommended Allowances in Designing for Forging. Forging draft is necessary to effect removal of the forging from the final or finishing die impression. Standard practice indicates the use of a 7° outside draft angle and a 10° inside draft. However, these angles may be varied from as low as 1° up to 15°, depending upon the material being used and the design of the part. There are cases requiring the design of forgings without draft in some portions of the product. If draft is absolutely necessary to produce these parts, special subsequent operations, such as sizing, may be used to remove the draft. Specialized knowledge and experience are necessary to determine the adaptability of forging design along these lines.

Radii and fillets which indicate a change in the direction of metal flow should be as large as possible, design permitting. Sharp radii and fillets increase the tendency toward forging defects, and cause undue die wear, thus increasing costs. Sharp corners on the forgings require correspondingly small fillets in the dies, and these small fillets increase the difficulty of filling the die impressions. Forging impact pressure on such sharp fillets may also develop die cracks at those points. Good design indicates long sweeps and large radii to promote economical, uniformly sound forgings.[1]

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[1] Discussion under the heading "Recommended Allowances in Designing for Forging" is adapted from matter contained in *The Improvement of Metals by Forging*, published by the Steel Improvement and Forge Company, Cleveland, Ohio, 1948.

Standard dimensional tolerances for commercial forging practice on closed-impression die forgings are outlined in Chapter XVI of this text. These have been compiled by the Drop Forging Association of Cleveland, Ohio.

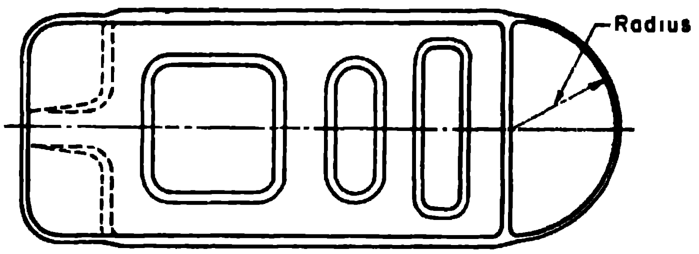
Surface Conditions and Special Requirements. The shape of the forged part has a considerable influence upon its surface condition. Also, the kind of material specified, the type of heating given the metal previous to forging, and the sequence of forging operations, have a bearing on the surface conditions of the product. In the event of forging some special products requiring extra-smooth surfaces, the die equipment for them must be carefully designed and built to meet the specified conditions. Also, the process handling is planned and carried out with extra precautions that better assure accomplishment of the required result.

The forging specifications should be clearly stated. If special requirements of weight, surface, balance, straightness, close hardness range, close composition tolerance, etc., are decided upon, they should be fully set forth. Otherwise, it must be assumed that commercial tolerances and conditions, listed in Chapter XVI of this text, apply to the forging. The more information that is given about a forging and its intended use, the better and easier will production of a specialized part be.

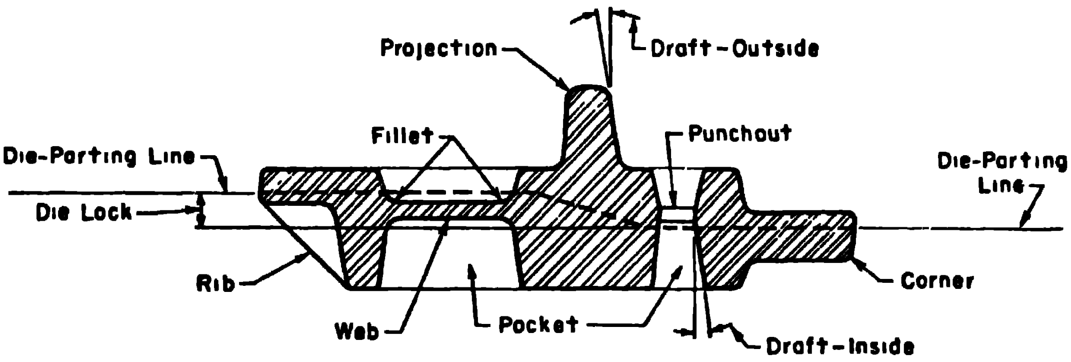
Pockets, Recesses, Ribs, and Thin Sections. Whenever pockets and recesses are required in forgings, the dies must be designed with corresponding raised sections, in order to restrict the flow of metal. If these sections are thin or high, they may heat up to a much higher temperature than the rest of the die, and cause rapid wear on the projection. This, in turn, reduces the depth of the pocket in the forging. Therefore, where pockets and recesses are required in the forging, connecting sweeps and draft angles that are as generous as possible should be designed. However, amplitude of sweeps and draft should stop short of hampering the functional design of the forged part. When the part is assembled into a unit, the latter should function in service in accordance with specified requirements. In the case of small depressions or small holes, it is preferable to machine or drill them in the part after forging operations have been completed.

Ribs and thin raised sections in a forging require that corresponding thin pockets and crevices be machined in the dies. The heated metal entering the dies cools rapidly after it has partially filled these die pockets. If it does not flow in completely during the period when it retains sufficient heat, the forging may have unfilled rib sections. In die design, therefore, ribs should be kept as low and as wide as the design will permit. Full top radii and large draft angles on the rib sides should be used wherever possible.

If the thin sections occur parallel to the plane of the die-parting line, there is a possibility of rapid die wear. Such is the case because of the faster cooling of the metal at such points, and because it is often difficult to forge the part down to size, since the cooled portion of metal does not flow readily into the dies.



Plan View



Cross Section View

Fig. 1. Typical Design of Forged Part

Courtesy of The Steel Improvement and Forge Company, Cleveland, Ohio

Typical Design of Forged Part. Fig. 1 illustrates an example of a typical design of a commonly-used forged part. The plan view and cross-section view identify the forging terminology which should be used in making drawings of forgings. It will be noted that the cross-section view indicates that this example requires a set of locked dies. A description of this type of dies is given earlier in this chapter. Locked dies are used in this instance because the two pockets at the left, in Fig. 1, are separated by a web which is on a plane different from the one of the die-parting line required for the right-hand portion of the part. In designing forged parts, it is preferable to keep the die-parting line in a single plane whenever possible, thereby avoiding the need for locked dies.

Basis for Selecting Forging as a Manufacturing Process. There are numerous advantages obtained through the use of forged parts. Some of these advantages are treated extensively in the previous chapters of this text. One important advantage is that forgings, if successfully manufactured, are free from concealed or internal defects. This accounts for fewer rejects at the forge shop and during subsequent manufacturing processes. It also makes for greater safety and maximum efficiency in service.

Another important advantage obtained through the use of the forging method is the uniformity of duplicate forged parts that is accomplished by the employment of closed-impression dies and the maintenance of quality control throughout the sequence of operations from raw material to finished product. Also, the close dimensional tolerances attained with closed-impression dies permit design of a forged part that eliminates rough machining and reduces finish machining to a minimum.

Among the most important factors which dictate the selection of a forged product are the strength and toughness of forgings. A properly selected forging method will produce a part that can meet very difficult conditions in actual service. Even if the cost of forging were higher than that of other manufacturing methods which could produce the identical shape, the forging method would still be preferred. It assures the required uniformity, strength, and toughness in the manufactured part.

Selection of a Suitable Forging Metal. The selection of a suitable forging material is of prime importance in the design and fabrication of forged products. The selection of material best suited to meet anticipated service requirements is very often a major problem. Modern metallurgy has developed a wide selection of metals in many of which various physical properties are duplicated. Routine tests usually determine the mechanical and metallurgical properties of the materials. For crankshafts, tensile-strength tests, and hardness and impact tests are usually made from test bars cut in a longitudinal direction from the work piece. Photomicrographs are made of some materials, such as crankshaft metals, after carefully prepared specimens have been subjected to an acid etch in a solution consisting of 4 parts nitric acid and 96 parts alcohol.

Fatigue tests are also made on some materials for forgings to determine their fatigue strengths. These tests entail use of special apparatus. Bending stresses are induced in parts, such as crankshafts, in one plane without any rotation of the part itself. Specially designed instruments record the test data. Strain gages are used to measure the stresses induced in the material.

Metals for forgings are available in a great variety of compositions. Both ferrous and nonferrous metals and their alloys are used for forgings. In the ferrous group, steel is the principal metal shaped by the various forging processes. Steels are the predominant forging metals, and are selected for composition by their AISI (American Iron and Steel Institute) numbers. Steels are also selected for properties by some standard specifications, such as given by ASM (American Society for Metals), ASTM (American Society for Testing Materials), and others. *Metals Handbook*, published by the American Society for Metals of Cleveland, Ohio, contains extensive information and data relative to forging metals. The student is urged to familiarize himself with this source of information and other sources as well. The Bibliography at the end of this book lists a number of such sources. It is beyond the scope of this text to devote space to the detailed properties of forging metals.

REVIEW QUESTIONS

1. How are the basic shape and size of a forged part determined?
2. Discuss the influence of a product designer upon the quality of a forged part.
3. What are locked dies?
4. What is standard practice with respect to draft allowance in a forging?
5. What is standard practice with respect to radii and fillets in forgings?
6. What factors have influence upon the surface conditions of a forging?
7. What provision is made in forging dies when pockets, recesses, ribs, and thin sections are required in the forged product?
8. Discuss how parting lines are determined in forging dies?
9. What is the basis for selecting forging as a manufacturing process?
10. Discuss the importance of selecting a suitable forging metal.
11. What types of metals are recommended for forging?

CHAPTER XV

Safety in Forging Operations

Prevention of Injuries to Operators. In plants and divisions of plants where forging processes are conducted, adequate safeguards in plant layout and shielding of machinery must be provided. Similar safeguards are necessary in connection with the handling of equipment and tools used in the various production processes.

Common accidents, such as burns, result from improper handling of hot metals. Careless operation of forging hammers and lack of safety devices are responsible for serious injuries to the arms, hands, and fingers of operators. For an operator to remove his goggles while operating any piece of hot-forming equipment is to risk serious injury to the eyes. In most hot-forming operations, danger from flying particles of hot metal is present.

Many modern plants install various types of safety shields as a means of preventing injury from flying particles of metal. The operators themselves should be trained to exercise caution with respect to their personal safety and that of fellow workers.

Safeguarding of all machinery, equipment, tools, and working procedures must be carried out, so that operators will not come in contact with dangerous moving parts of machines in operation.

Materials-handling equipment such as conveyors, moving cranes, and hoisting mechanisms should be installed with regard for the safety of workers. Warning signs that are conspicuously posted in danger zones are useful in preventing accidents. Eye-catching posters mounted on bulletin boards are effective in promoting safe work practices in the shop.

All types of shafting, whether overhead or installed under benches, and whether vertically positioned or inclined, should be well guarded. Clutches, couplings, projecting ends of shafts, keys, setscrews, and other projecting parts of revolving members should be housed or shielded. Gears, friction drives, and sprocket and chain units should be either completely enclosed or protected in some satisfactory manner. Belts, pulleys, balance wheels, and flywheels must be guarded so that the operator does not come in contact with these parts, or with other power-transmission equipment in motion.

National and State Safety Code Regulations. Several organizations have co-operated to the fullest extent and have expended considerable effort in instituting safe work practices for the protection of industrial workers in forging plants. Among these organizations are: the American Standards Association; the United States Department of Labor, the United States Bureau of Labor Statistics; the National Safety Council, Incorporated, of Chicago; other federal, state, and municipal public welfare departments; and safety promotion agencies of prominent insurance companies. Recommended safe practices cover many divisions of forging manufacturing. Some of these divisions are. materials handling by conveyer systems and accessory equipment, fabrication by various types of forging machinery, tooling, and cleaning and finishing of forgings.

Safety Measures. Limitation of space does not permit lengthy description of all the safety devices and measures used in the industrial forge shops, as well as in the school shops. However, some widely adopted safety measures designed to protect workers and trainees are stressed briefly in the following paragraphs.

Among the jobs which might be classified as hand work, in the forge shop and school alike, are a number of miscellaneous operations, such as running the gas furnace and handling the forged work. The worker whose job brings him in proximity to dangerous substances such as acids, potassium cyanide, sodium cyanide, liquid fuel, heated metals, etc., must be most safety conscious.

The gas furnace should never be operated without permission and without knowledge of how it is operated. The proper instructions should be carefully read before starting a forge or furnace. The foreman or instructor should be present, if necessary, when lighting the furnace. Goggles should be worn when lighting the furnace. In lighting a furnace, paper is inserted into the combustion chamber, and then the large main valve on the gas line is turned open; precaution is taken that all other valves are closed. The paper is then ignited, and after it is burning well, the air is turned on. The gas is turned on in the next step, while the paper continues to burn. Precaution must be taken not to turn on gas and then air—such a procedure will cause an explosion. When shutting off the furnace, the gas is turned off first and then the air. In any case, the furnace should not be allowed to reach an excessive temperature. Upon completion of the work and shutting off of the furnace, all gas valves and the main valve are closed.

When handling the forged work proper, an operator should watch for hot material and identify it in some manner if it is left lying on the floor. Proper tongs shall be selected to hold the work and keep it from slipping. Care and thoughtfulness can help reduce accidents. When quenching hot work, an operator should prevent water from coming in contact with hot oil, babbitt, lead, or cyanide of potassium. If oil is heated, it should not be allowed to become too hot and catch fire. In case of fire, knowledge of confining and stopping an oil fire is essential.

In handling cyanide, it must be remembered that it is poisonous and should be handled very carefully. One precaution is to keep cyanide away from all acids. Dry gloves should be worn when handling cyanide. It should never be allowed to come in contact with open wounds or skin abrasions. Hands should be washed thoroughly with running water after handling cyanide. Blindness or death may be the result of improper handling. Cyanide should be preheated before putting it in the cyanide pot to prevent splashing. No fire hazard is involved in handling cyanide.

Liquid fuels should be treated with care. Hands must not be washed in gasoline or similar compounds. They may cause an infection in the smallest cut. Gasoline should be used for cleaning parts only. It should never be used around an open flame, in a closed room, or near a hot surface. The gasoline torch should be handled carefully, and instructions on its operation should be read and observed. Leaded motor fuel should not be used in a torch, and an excess of air should never be pumped in the torch. Gasoline should be kept in safety cans, in small amounts. The National Safety Council of Chicago, the United States Department of Labor, and similar safety organizations have a large collection of useful information on safety measures and precautions. This extensive information has been published and may be obtained by applying for it. The information is published in form of bulletins, such as Bulletin No. 451, *Safety Code for Forging and Hot Metal Stamping,* issued by the United States Department of Labor, Bureau of Labor Statistics.[1]

REVIEW QUESTIONS

1. What causes common accidents in the forge shop?

2. What can prevent injuries to operators in the forge shop?

3. Discuss the advantage of using materials-handling equipment in the forge shop.

4. Discuss the function of national and state safety organizations with respect to the forge shop.

5. What safety measures are to be observed when one is operating a gas furnace in the forge shop? Handling liquid fuels?

6. What safety measures are required when one is handling acids?

7. What precautions are to be taken when one is handling hot forged work?

8. Discuss the contributions of the National Safety Council toward safety maintenance in the forge shop.

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[1] Discussion under the heading "Safety Measures" is adapted from matter contained in *A Good Mechanic Seldom Gets Hurt* by H. R. Graman, published by the American Technical Society, Chicago, Illinois, 1943

CHAPTER XVI

Standard Practices and Tolerances for Impression Die Forgings

Introduction. To summarize the discussion of forging techniques given in the foregoing chapters, and also to present industry-approved standards of practice, this chapter provides standard definitions and working specifications. These have been adopted by the Drop Forging Association and published in its *Standard Practices and Tolerances for Impression Die Forgings*. They are quoted here with permission. The practices and tolerances described apply to forgings that weigh under 100 pounds.

PRACTICES

Definition. A forging is the product of work on plastic metal formed to a desired shape by pressure. Modern duplicate forgings are formed in dies in a drop hammer, forging machine, or forging press. The forging hammer imparts intermittent impact pressure, and the forging machine (upsetter) and the forging press impart squeeze pressure. While some metals, including a few steels, can be cold forged, the majority of metals are made plastic for forging by heating.

Characteristics. The predominant characteristic of the forging is its tough, fibrous structure. This is first produced by elongation of the cast ingot grain in the rolling mill reducing operations to obtain forging bars, and is additionally refined by the forging operations. The dense fibrous structure imparts properties to the forging not obtainable in metal by other processes. The direction of these fibers, known as grain flow, can be controlled in the forging to give the toughness where it is most needed.

The special properties of forgings are:

1. A homogeneous structure, free from voids, blowholes, and porosity.

2. Greater strength per unit of cross-sectional area under static loads, and better resistance to shock.

3. Superior machining qualities. The uniform structure permits higher machining speeds; the freedom from imbedded impurities allows longer tool life and fewer grindings; and homogeneity reduces machining scrap.

Impression Die Forgings. *Impression die forgings* are made with suitable dies and tools to produce commercially exact duplicates in sufficient quantities to warrant the cost of dies and tools. Simple impression die forgings can be made by one pair of dies, but in order to obtain proper flow of metal in more complicated forgings, a combination of forging dies is more usual.

1. Drop forgings are made in a drop hammer or press containing a pair of matched dies with forming steps and impressions.

2. Upset forgings are usually produced in a forging machine or upsetter which contains a set of gripping dies with the necessary forming steps and a ram to force the metal into the die impression.

Forgeable Metals. An almost unlimited variety of forging metals is available in ferrous and nonferrous analyses. An exhaustive treatment of forgeable metals and their characteristics may be found in textbooks on forging and metallurgy, but the following are general classifications:

1. *Carbon Steels:* a. Low-carbon (up to 0.25%) forgings for moderate conditions and for carburized parts where resistance to abrasion is important. b. Medium-carbon (0.30% to 0.50%) forgings for more severe service. Some heat treatment is generally desirable. c. High-carbon (above 0.50%) forgings for hard surfaces and springs. Heat treatment is essential.

2. *Alloy steels (manganese, nickel, nickel-chromium, molybdenum, chromium, vanadium, chromium-vanadium, tungsten, silicon-manganese)*: These steels, as the name implies, are alloys of carbon steel with one or more additional elements. Forgings from these steels are used wherever higher strength, resistance, durability, etc., are wanted. The proper selection of a particular analysis, together with its subsequent heat treatment, depends upon the particular service re-

quirements of the part in question and is within the province of the metallurgist in consultation with the forging engineer.

3. *Corrosion and Heat-Resisting, and Stainless Steels:* The steels commonly used for resistance to corrosion or stain and for heat resistance are very high alloy steels usually high in chromium or nickel or both. The particular type of corroding agent present determines the best analysis. Generally, but not necessarily, forged surfaces should be polished to obtain full benefit of corrosion resisting properties.

4. *Iron:* Either wrought iron or ingot iron is forged for special applications where ductility is required. Wrought iron furnishes a moderate degree of corrosion resistance. The copper-bearing irons and low-carbon steels are in this class.

5. *Copper, Brasses, Bronzes:* Copper forgings have extensive application in the electrical field. The brass and bronze alloys have moderate corrosion-resistant properties. Some of the bronzes have moderately high strength and good bearing properties.

6. *Nickel and Nickel-Copper Alloys:* Pure nickel is forgeable. The alloy of nickel and copper known as Monel metal offers a desirable combination of strength, toughness, and corrosion resistance.

7. *Light Alloys (Aluminum, Magnesium)·* The light alloys have about one-third the weight of steel and some have been developed to approximately the strength of low-carbon steel. Forgeable alloys are available in both the aluminum and magnesium groups.

Commercial Forging Practice. Impression die forgings are sold by the piece and not by the pound. It is understood without specific mention that the excess metal or flash of forgings shall be removed by trimming, and that forgings shall be free from injurious defects.

1. *Quantity:* The quantity specified permits standard practice limits on over-runs and under-runs.

2. *Size:* Forgings within commercial size limits will be furnished unless closer tolerances are specified.

3. *Coining or Sizing:* Closer tolerances may be obtained by additional hot or cold sizing operations.

4. *Surface Conditions:* Forgings are generally, but not always furnished in a cleaned condition by either tumbling, pickling or blast-cleaning.

5. *Special Requirements:* Any special requirement, such as heat treatment or special tests, should be clearly stated.

6. *Dies:* Impression die forgings require special dies and tools for

their production. The original charge for dies and tools conveys exclusive use but does not permit removal without additional payment. Dies and tools are maintained without additional charge.[1]

TOLERANCES

Tolerances shall be either "Special" or "Regular."

"Special" Tolerances are those which are particularly noted in the specifications and may state any or all tolerances in any way as occasion may require. Special Tolerances apply only to the particular dimension or thing noted. In all cases where Special Tolerances are not specified, Regular Tolerances shall apply.

"Regular" Tolerances are divided into two divisions—"Commercial Standard" and "Close Standard." "Commercial Standard" tolerances are for general forging practice, but when or where extra close work is desired involving additional expense and care in the production of forgings, "Close Standard" may be specified. "Close Standard" may be specified for one or more of the following classes. When no standard is specified, "Commercial Standard" shall apply.

Classes. Regular Tolerances are applicable to the following classes:

1. Thickness
2. Width
   a) Shrinkage and Die Wear
   b) Mismatching
   c) Trimmed Size
3. Draft Angle
4. Quantity
5. Fillets and Corners.

Class 1, Thickness Tolerances. Thickness tolerances shall apply to the over-all thickness of a forging. When applied to drop hammer forgings, they shall apply to the thickness in a direction perpendicular to the main or fundamental parting plane of the die. When applied to upset forgings, they shall apply to the thickness in a direction parallel to the direction of travel of the ram, but only to such dimensions as are enclosed by and actually formed by the die.

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[1] The foregoing content of this chapter is from the *Handbook of Commodity Data Sheets,* published by The National Association of Purchasing Agents. Reprinted by Drop Forging Association, with permission.

TABLE V. THICKNESS TOLERANCES (INCHES)

Net Weights up to—lbs.	Commercial		Close	
	−	+	−	+
0.2	0.008	0.024	0.004	0.012
0.4	0.009	0.027	0.005	0.015
0.6	0.010	0.030	0.005	0.015
0.8	0.011	0.033	0.006	0.018
1.0	0.012	0.036	0.006	0.018
2.0	0.015	0.045	0.008	0.024
3.0	0.017	0.051	0.009	0.027
4.0	0.018	0.054	0.009	0.027
5.0	0.019	0.057	0.010	0.030
10.0	0.022	0.066	0.011	0.033
20.0	0.026	0.078	0.013	0.039
30.0	0.030	0.090	0.015	0.045
40.0	0.034	0.102	0.017	0.051
50.0	0.038	0.114	0.019	0.057
60.0	0.042	0.126	0.021	0.063
70.0	0.046	0.138	0.023	0.069
80.0	0.050	0.150	0.025	0.075
90.0	0.054	0.162	0.027	0.081
100.0	0.058	0.174	0.029	0.087

Class 2, Width and Length Tolerances. Width and length tolerances shall be alike and shall apply to the width and/or length of a forging. When applied to drop hammer forgings, they shall apply to the width or length in a direction parallel to the main or fundamental parting plane of the die, but only to such dimensions as are enclosed by and actually formed by the die. When applied to upset forgings, they shall apply to the width or length in a direction perpendicular to the direction of travel of the ram.

Width and length tolerances shall consist of three subdivisions:

Class 2 (*a*). Shrinkage and die wear tolerance

Class 2 (*b*). Mismatching tolerance

Class 2 (*c*). Trimmed size tolerance.

Class 2 (a), Shrinkage and Die Wear Tolerances. Shrinkage and die wear tolerances shall apply to that part of the forging formed by a single die block only. They shall not apply to any dimension crossing the parting plane. They shall be the sum of the shrinkage tolerances and the die wear tolerances as given in Table VI. The shrinkage tolerances and die wear tolerances shall not be applied separately, but shall only be used as the sum of the two. They shall not be so applied as to include draft or variation thereof.

Class 2 (b), Mismatching Tolerance. Mismatching is the displacement of a point in that part of a forging formed by one die

TABLE VI. SHRINKAGE AND DIE WEAR TOLERANCES (INCHES)

Shrinkage			Plus Die Wear		
Lengths or Widths up to—In.	Commercial + or −	Close + or −	Net Wt. up to—Lbs	Commercial + or −	Close + or −
1	0.003	0.002	1	0.032	0.016
2	0.006	0.003	3	0.035	0.018
3	0.009	0.005	5	0.038	0.019
4	0.012	0.006	7	0.041	0.021
5	0.015	0.008	9	0.044	0.022
6	0.018	0.009	11	0.047	0.024
Each additional inch add	0.003	0.0015	Each additional 2 lbs. add	0.003	0.0015
For example			For example		
12	0.036	0.018	21	0.062	0.031
18	0.054	0.027	31	0.077	0.039
24	0.072	0.036	41	0.092	0.046
36	0.108	0.054	51	0.107	0.054

block of a pair, from its desired position when located from the part of the forging formed in the other die block of the pair. Mismatching does not include any displacement caused by variation in thickness of the forging, but is only the displacement in a plane parallel to the main or fundamental parting plane of the dies.

Mismatching tolerances are independent of, and in addition to, any other tolerances.

TABLE VII. MISMATCHING TOLERANCES (INCHES)

Net Weight up to—Pounds	Commercial	Close
1	0.015	0.010
7	0.018	0.012
13	0.021	0.014
19	0.024	0.016
Each additional 6 lbs. add	0.003	0.002
For example—		
37	0.033	0.022
55	0.042	0.028
79	0.054	0.036
97	0.063	0.042

Class 2 (c), Trimmed Size Tolerances. The trimmed size shall not be greater nor less than the limiting sizes at the parting plane imposed by the sum of the draft angle tolerances and the shrinkage and die wear tolerances.

Class 3, Draft Angle Tolerances. Draft angle tolerances are the permissible variations from the standard or nominal angle of draft.

Table VIII. Draft Angle Tolerances for Drop Hammer Forgings (Degrees)

	Nominal Angle	Commercial Limit Maximum	Close Limit Maximum
Outside	7	10	8
Inside holes and depressions			
Commercial limits	10	13	
Close limits	7		8

Table IX. Draft Angle Tolerances for Upset Forgings (Degrees)

	Nominal Angle	Commercial Limit Maximum	Close Limit Maximum
Outside	3	5	4
Inside holes and depressions	5	8	7

Class 4, Quantity Tolerances. Quantity tolerances shall be the permissible over- or under-run allowed for each release or part shipment of an order. Any shipping quantity within the limits of over-

Table X. Quantity Tolerances

Number of Pieces on Order	Over-Run	Under-Run
	Pieces	Pieces
1– 2	1	0
3– 5	2	1
6– 19	3	1
20– 29	4	2
30– 39	5	2
40– 49	6	3
50– 59	7	3
60– 69	8	4
70– 79	9	4
80– 99	10	5
	Per Cent	Per Cent
100– 199	10	5.0
200– 299	9	4.5
300– 599	8	4.0
600– 1,249	7	3.5
1,250– 2,999	6	3.0
3,000– 9,999	5	2.5
10,000– 39,999	4	2.0
40,000–299,999	3	1.5
300,000 up	2	1.0

and under-run shall be considered as completing the order. Commercial and close tolerances shall be the same amounts.

Class 5, Fillet and Corner Tolerances. Fillet and corner tolerances apply to all meeting surfaces even though drawings and/or models indicate sharp corners, unless such drawings and/or models have or indicate (even though actual dimensions are not specified) fillet and/or corner dimensions of larger radii than the following standards, in which case such actual or indicated larger dimensions shall be considered as actually specified and the tolerances shall be "Special Tolerances."

Fillet tolerances apply to inside corners and edges in all cases in which surfaces meet at an angle less than 180 degrees.

Corner tolerances apply to outside corners and edges in all cases in which surfaces meet at an angle greater than 180 degrees.

Where a corner tolerance applies on the meeting of two drafted surfaces, the tolerance shall apply to the narrow end of such meeting and the radius will increase toward the wide end. The total increase in the radius will equal the length of the drafted surface in inches, multiplied by the tangent of the nominal draft angle.

The radii of fillets and corners may be any value not greater than those given in Table XI.

TABLE XI. FILLET AND CORNER TOLERANCES (MAXIMUM RADII IN INCHES)

Net Weights up to—Pounds	Commercial	Close
0.3	3/32	3/64
1.0	1/8	1/16
3.0	5/32	5/64
10.0	3/16	3/32
30.0	7/32	7/64
100.0	1/4	1/8

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Dominion Forge & Stamping Co., Ltd., Walkerville, Ont.
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Kropp Forge Co., Chicago, Ill.
The National Machinery Co., Tiffin, Ohio
The Steel Improvement & Forge Co., Cleveland, Ohio
Wyman-Gordon Co., Harvey, Ill.

Glossary of Forging Terms[1]

A

abnormal steel: A steel which does not develop a uniform case hardness when carburized.

acid steel: Steel of any kind which has been subjected to acid reaction in melting, as from the bottom, lining or slag in the furnace.

aging: The spontaneous change in the properties of a metal which occurs at relatively low temperature following a final heat treatment or a final cold working operation. Aging tends toward the restoration of real equilibrium in the metal, and away from any unstable condition induced by a prior operation.

air-hardening steel: A steel which does not require liquid quenching from a high temperature to harden, but is hardened by simply cooling in air from above the critical range.

alloy: A material, usually metal, containing two or more elements, which are soluble or partly so in each other in the liquid state.

alloy steel: Steel which contains, in addition to the normal elements of iron, carbon, and manganese, one or more elements in sufficient quantity to impart certain additional desirable properties. The small amounts of elements and impurities such as sulphur, silicon, phosphorus, and aluminum which are usually present in any steel, are not considered alloys. If manganese is added to steel in sufficient quantity, it may be considered as an alloy in alloy steel.

anneal: Heating steel to above its critical range, holding it at that temperature a sufficient length of time for the steel to be heated entirely through its full area, and slowly cooling it through the critical range. Cooling may be performed by cooling the steel down slowly with the furnace, or by burying the steel in dry ashes or lime. Annealing is to remove all working strains and to impart softness to the steel.

anvil: The block of iron or steel upon which metal is forged.

anvil cap or sow block: A block of hardened steel placed between the anvil and the forging die to relieve undue wear on the anvil.

austenitic steel: Steel containing alloys which set up the austenitic grain structure and make the metal nonmagnetic at ordinary temperatures.

auxiliary operations: Additional processing to the forging to obtain shapes, surface conditions, or other properties not obtainable in the regular forging operation.

B

basic steel: Steel made by any process, which has been melted in a furnace where the bottom, lining, and slag have basic reactions.

bender: The portion of the dies which forms the metal so that the longitudinal axis is in two or more planes.

Bessemer steel: Steel made by the Bessemer process of blowing air through molten pig iron contained in a suitable vessel.

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[1] Explanations given for terms in this Glossary are predominantly adopted from *Drop Forging Topics*, Vols. 14 and 15, 1950, published by the Drop Forging Association of Cleveland, and from *Glossary of Forging Terms*, published by the Kropp Forge Company of Chicago.

billet: A semifinished hot rolled metal ingot, with a rectangular cross section ranging from 4 to 36 square inches, the width being less than twice the thickness. Where the cross section exceeds 36 square inches, the term "bloom" is properly but not universally used. Sizes smaller than four square inches are usually termed "bars."

blast cleaning: A process for removing the oxide surface, or scale, from forgings by propelling grit or shot at high velocity against the work in order to clean it.

blocking: A forging operation which imparts to the forging its general but not exact or final shape

blocking impression: The impression which gives the forging its general shape.

bloom: A semifinished hot rolled metal ingot with a rectangular cross section of 36 square inches or more.

blooming mill: A mill in which metal ingots are reduced to blooms, billets, bars, slabs, and sheet bars.

blow: The impact or other pressure produced by the moving part of any forging unit.

blowhole: A hole produced during the solidification of metal by evolved gas which, failing to escape, is held in pockets.

board drop hammer: A drop hammer powered by gravity, so named because the falling parts are attached to a board.

boiler steel: A practically obsolete term applied to low carbon steels. It should not be used in describing forging steels, as more exact definitions are available.

boss: A projection on the surface of a forging, usually of cylindrical shape.

box anneal: An annealing process whereby the steel to be annealed is packed in a closed container to protect the surfaces from oxidation.

Brinell hardness: The hardness of a metal or part, as represented by the number obtained from the ratio between the load applied on and the spherical area of the impression made by a steel ball forced into the surface of the material tested.

burnt steel: Steel which has been heated so close to the melting point as to cause permanent injury to the extent that it cannot be reclaimed for further heat treatments.

C

carbon steel: Steel in which the physical and mechanical properties depend primarily upon the carbon content.

carburize: Adding carbon to low carbon steel by heating to above the critical range in contact with some carbonaceous material. Commercially, the carbon is added to the outer section of the steel so that when a subsequent heat treatment is added, the outer surface has a greater hardness than the core.

case-hardening: A heat treatment or a combination of heat treatments in which the surface layer of an iron-base alloy is made substantially harder than the interior by altering its composition. Method used might be carburizing, cyaniding or nitriding.

check: A crack in a die impression, usually in a corner, generally due to forging strains localized at some relatively sharp corner.

clean: The operation of removing the oxide coating, or scale, from the surface of the forging.

cogging: The reducing operation of working an ingot into a billet or bloom by means of a hammer or press; also rolling.

coining: The operation of applying heavy pressure in a coining press to a surface to obtain closer tolerances or smoother surfaces. In the strict sense, the term should be "sizing."

coining dies: Dies used in performing the coining or sizing operation.

cold shut: (1) A portion of the surface of a metal piece which is not integral with the main mass. This usually results from rolling or forging into the piece a separate or partially separate piece of metal, such as that which spatters on the surface of an ingot or mechanical projections. (2) The freezing over of the top surface of an ingot before the mold has been filled, due to an interruption of the stream of metal. (3) A portion or fin pinched between the forging dies when rolling or shaping the billet or bar, which, on quartering on the following blow of the hammer, impresses the fin into the forging and fuses it so close that it can hardly be seen with the naked eye and can only be detected by magnetic inspection, but if allowed to remain in the forging would have a tendency to weaken it at that point.

cold working: Permanent plastic deformation of a metal at a temperature below its recrystallization point; low enough to produce strain hardening.

consumed weight: The weight of received material expended, divided by the number of forgings accepted by the customer. All scrap rejects and material loss from any cause are included.

critical temperature: The temperature at which allotropic transformation (changes in structure) takes place in metal.

cutoffs: A pair of blades, either milled in the corner of a pair of forging dies, or inserted in the dies, used to cut away a forging from the bar after the finishing blow.

cut weight: The weight of material necessary at the machine to fabricate one forging. This equals the net weight plus flash, sprue, tonghold, and scale loss.

D

die: A steel block into which desired impressions are machined, and from which forgings are produced. Forging dies usually come in pairs, with part of the impression in each block.

die forgings: Forgings which are produced in dies, including drop forgings and upset forgings.

die shift: The movement of the dies from their proper place in relation to each other.

draft: The amount of taper on the side walls of die impressions to aid the removal of the forging from the dies. Applied also to the metal on a forging caused by this taper.

draft angle: The taper of the draft expressed in degrees.

drawing: Reheating after hardening to a temperature below the critical range, followed by any desired rate of cooling; the term "tempering" has the same meaning.

drop forging: (*See* **forging**) A forging made in a drop hammer.

E

edger: The portion of the die that distributes the metal in a general proportion of the shape to be forged.

elongation: The amount of permanent stretch in a test specimen before rupture, usually expressed as a percentage of the original length, such as 25 per cent in 2 inches.

endurance limit: A limiting stress, below which metal will withstand an indefinitely large number of cycles of stress without fracture. Above this limit, failure occurs by the generation and growth of the cracks until fracture results.

F

fatigue: The progressive fracture of a metal by means of a crack which enlarges under repeated cycles of stress.

fatigue limit: Usually used as a synonym for endurance limit.

fiber: A characteristic of wrought metal, including forgings, manifested by a fibrous and woody appearance of fractures and indicating directional properties Fiber is caused chiefly by the extension of the constituents of the metal in the direction of working.

fillet: The radius imparted to inside meeting surfaces, such as the radii of the impressions in forging dies.

fin: (*See* **flash**) The metal that is in excess of that required to fill out the final impression in a pair of dies and moves out as a thin plate around the parting line of the dies

final yield: The quotient obtained by dividing the net weight by the consumed weight.

flash: The metal that is in excess of that required to fill out the final impression in a pair of dies and moves out as a thin plate around the parting line of the dies Also called fin.

flash pan: The portion of the dies which has been machined to permit the excess metal to flow through.

forging: The product of work on plastic metal formed to a desired shape by pressure. Forgings are formed in dies in a drop hammer, forging machine, or forging press. The forging hammer imparts intermittent impact pressure, and the forging machine (upsetter) and the forging press impart squeeze pressure. While some metals, including a few steels, can be cold forged, the majority of metals are made plastic for forging by heating.

forging quality steel: Steel which has been so processed as to remove defects undesirable in forgings.

forging strain: A strain that has been set up in the metal by the process of forging. It may be relieved by a subsequent annealing or normalizing.

fracture test: Breaking a piece of metal for the purpose of detecting internal defects or determining the structure of the metal by examination of the fractured surface.

fuller: That portion of the die used for reducing the cross section of the stock.

gathering stock: Any operation whereby the cross section of a portion of the stock is increased above its original size.

grain: Crystals in metal which form the structure.

grain flow: The direction of flow lines in a forging.

grain size: The size of crystals in metal when measured with some standard.

gross weight: The weight required to produce one forging. May have the meaning of cut weight or multiple bar weight or consumed weight. See those definitions.

gutter: The portion of the die which has been relieved to provide for the excess metal after it passes through the flash pan

H

handling holes: Holes drilled in opposite ends of the die block to permit handling by the use of a crane or bar.

hardening: A method of increasing the hardness of a metal by controlled heating and cooling.

hardness: Generally, the resistance of metal to deformation by mechanical force. Also refers to the hardness numbers obtained in testing for hardness by any of the several hardness tests.

heat: Amount of forging stock placed in the batch type of forge-heating furnace, to be heated up at one time. Also, temperature of the metal, or the operation of increasing the temperature of the metal, for heat treating or forging purposes.

heat of steel: The batch of steel manufactured from one melt

heat treatment: Any operation or operations of heating metal and cooling it in order to bring out desired physical properties.

helve hammer: A power hammer in which power is delivered through a helve or handle. Used in light work, tool making, and supplementary operations.

hot working: The mechanical working of metal at a temperature above its recrystallization.

hot working steel: Steel which is designed primarily for uses in dies and tools in which the metal being worked is in the heated state

hub: A boss which is in the center of the forging and forms a part of the body of the forging.

I

impression: That portion of the dies which has been machined so as to produce the shape of the forging

inclusions: Impurities in metal, usually oxides, sulphides, and silicates, which are held in mechanical mixture.

ingot: A casting made for subsequent rolling or forging.

insert: A piece of steel which is removable from a die The insert may be used to fill a cavity, or to replace a portion of the die with a grade of steel that is better adapted for service at that particular point.

insert die: A small die containing the impression of a forging and which is fastened in a master block

inspection: The process of checking a forging for possible defects or deviations from the standards given in the specifications Chemical inspection is the determination of the chemical analysis of the metal. Physical property inspection is the determination of the resistance of the metal to deformation against the application of force in several forms. Hardness testing is the determination of the relative hardness of the metal against a standard hardness when tested by one of several hardness tests. Cold inspection is a visual inspection of the forgings for visible defects, dimensions, weight, and surface condition. Hot inspection is a visual inspection of the forging for visible defects during the time the forgings are in the heated state.

iron: A press operation used to obtain a more exact alignment of the various parts of a forging, or to obtain a better surface condition.

L

lap: A surface defect in the forging caused by the folding of metal in a thin plate on the surface.

layout: The transference of drawing or sketch dimensions to templates or dies for use in sinking dies. Also checking a forging or a lead cast to determine whether its dimensions are in accordance with those given in the specifications.

lead cast: A reproduction in lead, or a lead alloy, of the die impression, obtained by clamping the two dies together in alignment and pouring molten metal into the finish impression. Also called a lead proof.

lock: One or more changes in the plane of the mating faces of the dies. A compound lock is one where two or more changes are in the mating faces. A counterlock is a lock placed in the dies to offset a tendency for die shift caused by a necessarily steep lock.

M

machinability: The relative ease of removing metal by machining, as applied to some specific metal.

machine forging: The process of forging in the upsetter or forging machine, in which the metal is moved into the die impression by the pressure of the moving punch, while the dies remain in position during the time the pressure is applied

macrostructure: The structure and internal condition of metals as revealed on a machined and etched sample, examined either by the naked eye or under low magnification.

magnafluxing: A nondestructive method of inspecting steel forgings, involving the use of patented equipment, by which subsurface defects and inclusions are detected and located with the aid of an induced magnetic flux.

matched edges: The machined surfaces of the dies at the parting plane at right angles to each other from which all measurements are determined. Sometimes called match lines or matched faces.

match lines: Two lines along right angle edges of the forging die block, from which all dimensions and alignments are taken.

mechanical properties (commonly called Properties): Those qualities which reveal the reaction of metal or other material to an applied force, or that involve the relationship between stress and strain. Examples: tensile strength, endurance limit.

mechanical working: Subjecting metal to pressure, exerted by rolls, hammers or presses, in order to change its shape or physical properties.

microstructure: The structure and internal condition of metals as revealed on a ground and polished (and sometimes etched) surface when magnified to high magnification.

mismatch: Two forging dies not in perfect alignment.

modulus of elasticity: The ratio, within the limit of elasticity, of the stress to the corresponding strain.

multiple bar weight: The cut weight plus loss in cutting as saw cut or torch burn. Crop ends from shearing may or may not be included.

N

net weight: The average shipping weight of all forgings shipped from one die sinking. Equals shape weight plus die wear and size tolerances.

normalizing: Heating steel to approximately 100° F. above the critical range, holding it at that temperature for the required time and cooling to below that range in still air at ordinary temperature.

O

open-hearth steel: Steel made by the open-hearth process, in which proportions of cast iron and scrap steel and/or molten pig iron is melted with suitable flux Contact and reaction with the slag that forms on top of the molten metal purifies to the desired requirement

overheating: Heating steel to such high temperatures that the grains become coarse, impairing the properties of the metal.

P

pad: (*See* **iron**) A press operation used to obtain a more exact alignment of the various parts of a forging, or to obtain a better surface condition

parting line: The intersection of the surface of the impression and the parting plane. Also the flash line on a forging.

parting plane: The dividing plane between the two halves of a pair of forging dies.

physical properties: Those properties covered in physics, exclusive of those classed under mechanical properties, for example, density, electrical conductivity, coefficient of thermal expansion.

pickling: Chemical treatment to remove scale from metal

planish: Rolling a forging, or some portion of a forging, in a pair of dies to remove the trim line or to obtain close tolerances. Generally, a cold press or hammer operation, but performed at low temperature at times.

platter: The entire mass of metal upon which the hammer performs work, including the flash, sprue, tonghold, and as many forgings as are made at a time.

press forging: A forging produced by a mechanical or a hydraulic press.

proof: Any reproduction of a die impression in any material. Usually obtained by clamping the dies together in alignment and pouring molten lead into the finish impression.

punch: The operation of shearing out a slug in a forging to produce a hole.

R

ram: The moving or falling part of a drop hammer or press, to which one of the dies is attached. Sometimes applied to the upper flat die of a steam hammer.

red shortness: Brittleness in metal when at red heat.

reducing atmosphere: A combustion condition in a furnace where there is a deficiency in oxygen or no excess oxygen. Also called "wet fire."

reduction of area: The difference, in a tensional test specimen, between the original sectional area and that of the smallest area at the point of rupture.

restriking: Striking a trimmed forging an additional blow in the dies to align its several components.

restriking on draw: Restriking a forging on the tempering heat of a heat treatment to produce closer alignment of sections.

Rockwell hardness: A method of measuring relative hardness on a Rockwell hardness testing machine. It uses the degree of penetration with a given indentor and load, the values being revealed on a dial indicator.

roller: A preparatory operation in a set of drop forging dies, designed to move bar forging stock into various forms of revolution so that the metal is distributed suitably for further forging in drop forging dies.

rolling edger: An edger and a roller combined for the distribution of metal for further forging in drop forging dies.

ruptured metal: Forging stock which has been hammered or worked so severely as to cause broken fibers in the metal. Applied particularly to thin sections.

S

sandblast: To clean forgings by propelling sand at high velocity by air pressure.

scale: The oxide film that is formed on hot metal by chemical action of the surface metal with the oxygen in the air.

scale pit: A surface depression formed on the forging due to scale in the dies during the forging operation.

scarf: The portion of a metal piece that has been shaped for welding.

Scleroscope hardness test: A test for hardness in metals, consisting of the drop and rebound of a diamond-tipped hammer enclosed in a glass tube.

seam: A crack on the surface of a forging. If very fine, it may be called a hair seam or hair crack.

shank: That portion of a tool by which it is held in position during use.

shape weight: The weight of material contained in the geometric volume to the specified dimensions.

shoe: A holder required as a support for the stationary portion of trimming or forging dies.

shotblast: Cleaning forgings to free them of scale by propelling fine steel shot at high velocity through centrifugal force, against the surface of the forging.

shrinkage: The contraction of metal when cooled.

sink: The specialized operation of machining impressions into forging dies.

size: The operation in a press to obtain closer tolerances on portions of a forging.

slab: A flat shaped, semifinished, rolled metal ingot with a width not less than 10" and a cross-section area not less than 16 square inches.

slug: Any small piece or wedge of metal.

Smith forging: A general term, applied both to hand forgings made by hand on an anvil, and also to hammer forgings made by a power hammer using flat dies.

Smith hammer: Any power hammer where impression dies are not used

soaking heat: Holding the metal at a desired temperature sufficiently long to permit the metal to reach a uniform temperature.

soft steel: An obsolete term sometimes used to designate low carbon steel. Sometimes called mild steel.

sprue: The portion of the die which is machined out to permit a connection between multiple impressions or between the impression and the forging bar Sometimes called gate

steam hammer: A power hammer used in making flat die forgings

stock: The portion of metal which has been cut for a given number of forgings.

straighten: Decreasing misalignment between various sections of a forging.

structure: The arrangement of the various phases comprised in the metal or alloy under consideration

surface peening: Shotblasting to increase the fatigue life of forgings.

swage: Operation of reducing or changing the cross-section area of diameters by revolving the stock under fast impact blows

tempering: (*See* **drawing**)

template: A gage or pattern made from a sheet and used to lay out or check dimensions on forgings or dies.

tensile properties: The property data obtained from tensile tests on a metal specimen, including tensile strength, elongation, reduction of area, and yield point.

tensile strength: The maximum load per unit of cross sectional area obtained before rupture in the tension test.

tolerance: The permissible deviation from the specifications.

tonghold: The portion of the stock by which the operator grips the stock with tongs during the forging operation.

tongs: Metal holder used to handle hot or cold metal pieces.

trim: To remove the flash or excess metal from a forging by a shearing operation. May be done hot or cold.

trimmer: The dies used to remove the flash or excess stock from the forging.

trimming shoe: The holder used to support the trimmer

tumbling: A process for removing scale from forgings by impact with each other, together with jacks, sawdust, and abrasive material, in a rotating container

type: A hardened block machine to the shape of a portion of the required forging and tapped in that part of the die impression to determine its shape

U

undercut: Sections which would lock themselves into a die impression, and prevent removal without distortion if driven into the impression while the metal is hot

underfill: The portion of a forging which does not have its true shape owing to insufficient metal.

upset forging: A forging in which the metal has been placed in the die so that the direction of the fiber structure is at right angles to the faces of the die.

upsetting: When a piece of stock is worked in such a way that its length is shortened and either or both its thickness and width increased, the piece is said to be upset and the operation is known as upsetting.

W

weight: *See* **shape weight, net weight, gross weight, cut weight, multiple bar weight, consumed weight.**

weld: Uniting metal by the application of heat.

Y

yield: (*See* **final yield**) The quotient obtained by dividing the net weight or the shape weight by the gross weight.

yield point: The load per square inch of original cross-sectional area which causes a marked increase in extension without increase of the load.

yield strength: Stress corresponding to some fixed permanent deformation, such as 0.1 per cent or 0.2 per cent offset from the modulus slope.

Appendix of Useful Tables

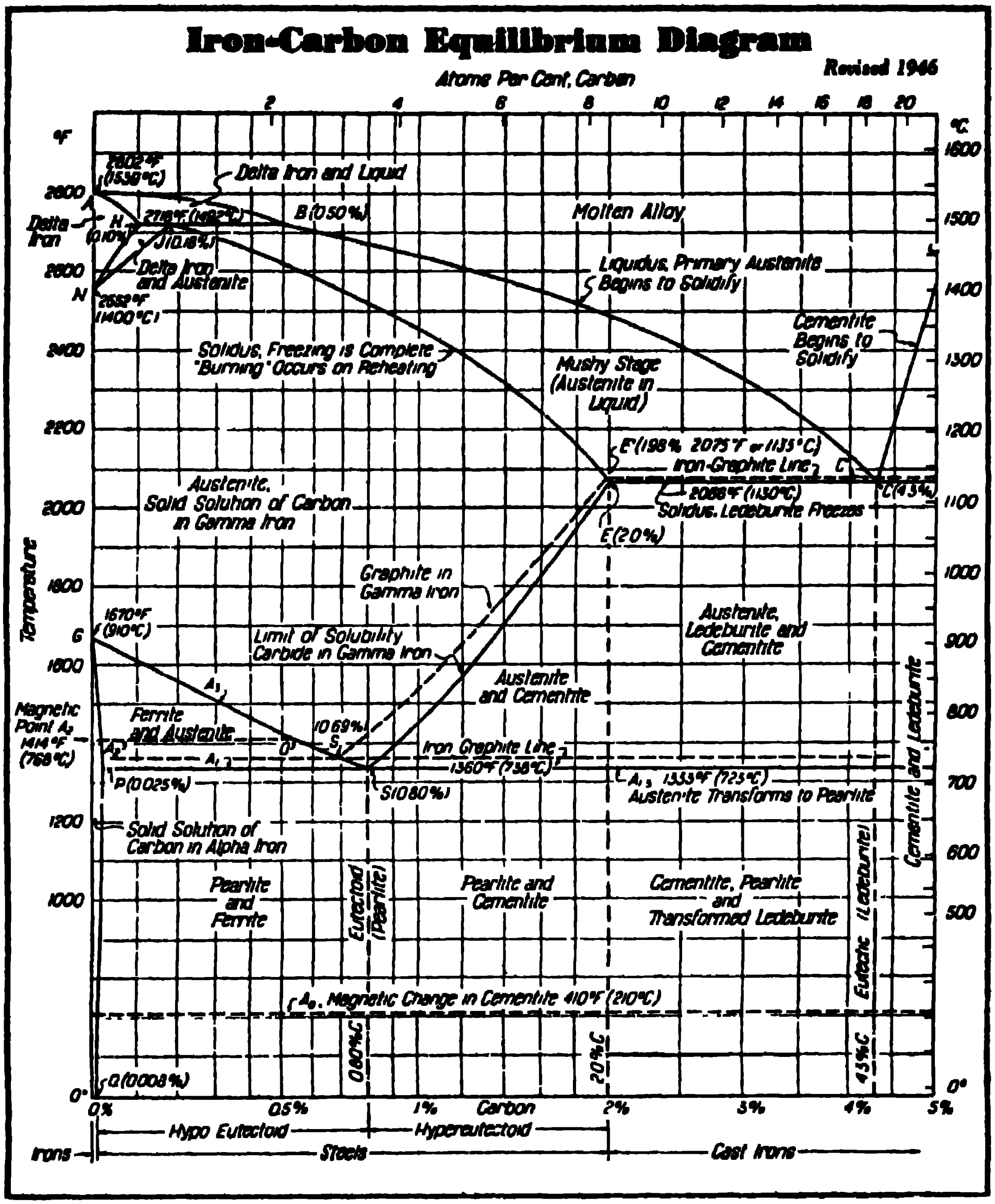
DECIMAL EQUIVALENTS OF COMMON FRACTIONS OF AN INCH

Common Fractions	Decimal Equivalents	Common Fractions	Decimal Equivalents	Common Fractions	Decimal Equivalents	Common Fractions	Decimal Equivalents
1/64	.015625	17/64	.265625	33/64	.515625	49/64	765625
1/32	.03125	9/32	.28125	17/32	53125	25/32	78125
3/64	046875	19/64	296875	35/64	546875	51/64	.796875
1/16	.0625	5/16	.3125	9/16	.5625	13/16	8125
5/64	078125	21/64	.328125	37/64	578125	53/64	828125
3/32	09375	11/32	34375	19/32	.59375	27/32	84375
7/64	.109375	23/64	.359375	39/64	.609375	55/64	859375
1/8	.125	3/8	.375	5/8	625	7/8	875
9/64	140625	25/64	390625	41/64	640625	57/64	890625
5/32	.15625	13/32	40625	21/32	.65625	29/32	90625
11/64	171875	27/64	.421875	43/64	671875	59/64	921875
3/16	.1875	7/16	4375	11/16	6875	15/16	9375
13/64	.203125	29/64	453125	45/64	703125	61/64	.953125
7/32	.21875	15/32	46875	23/32	71875	31/32	.96875
15/64	234375	31/64	.484375	47/64	734375	63/64	984375
1/4	25	1/2	50	3/4	75		

RECOMMENDED FORGING TEMPERATURES

For Various Types of Steels

Grade	Temperature	Grade	Temperature
1015	2250° F	4615	2350° F
1040	2200° F	4640	2300° F
2317	2300° F	4820	2300° F
2340	2200° F	5120	2300° F
2512	2300° F	5140	2200° F
3115	2250° F	6120	2250° F
3140	2250° F	6150	2250° F
3240	2200° F	8620	2050° F
3312	2250° F	8640	2200° F
4135	2200° F	8720	2200° F
4320	2300° F	8740	2200° F
4340	2300° F.	18-8	2400° F



The Iron-Carbon Equilibrium Diagram* graphically represents not only the freezing of all the iron-carbon alloys, but also the changes that take place after solidification and cooling to atmospheric temperatures. Such a diagram permits the selection of the proper range of temperatures for tapping of the molten metal, hot working, and heat treatment for all the iron-carbon alloys

The presence of any other elements influences the locations of the critical temperatures and since steel contains elements other than iron and carbon, their characteristics and the amounts of each must be considered for proper use of the diagram.

The freezing of the iron-carbon alloy is represented by the upper portion of the diagram and the solidification takes place when the metal is cooled below the imaginary line called the liquidus line. Solidification is completed when the temperature goes lower than the temperatures represented by the solidus line As the metal continues to cool, crystallization of the various components takes place, changing at locations which are known as critical temperatures and are shown on the diagram as *A1, A2, A3,* etc.

The diagram is divided into several sections, depending upon the carbon content, namely, hyper-eutectic containing 4.30 per cent carbon or more, hypo-eutectic containing less

DRAFT ANGLES

Depth	1°	2°	3°	5°	7°	10°	12°	15°
1/32″	.0005	.0011	.0016	.0027	.0038	.0055	.0066	1/64 − .008
1/16″	.0011	.0022	.0033	.0055	.0077	1/64 − .011	1/64 − .013	1/64 + .017
3/32″	.0016	.0033	.0049	1/64 − .008	1/64 − .0115	1/64 + .0165	1/64 + .020	1/32 − .025
1/8″	.0022	.0044	.0066	1/64 − .0109	1/64 − .015	1/64 + .022	1/32 − .027	1/32 + .033
3/16″	.0033	.0065	.0098	1/64 + .016	1/64 + .023	1/32 + .033	3/64 − .040	3/64 + .050
1/4″	.0044	.0087	.013	1/64 + .022	1/32 − .031	3/64 − .044	3/64 + .053	1/16 + .067
5/16″	.0055	.011	1/64 + .016	1/32 − .027	1/32 + .038	1/16 − .055	1/16 + .066	5/64 + .084
3/8″	.0065	.013	1/64 + .020	1/32 + .033	3/64 − .046	1/16 + .066	5/64 + .080	3/32 + .100
7/16″	.0076	1/64 − .015	1/64 + .023	1/32 + .038	3/64 + .054	5/64 − .077	3/32 − .093	1/8 − .117
1/2″	.0087	1/64 + .017	1/32 − .026	3/64 − .044	1/16 − .061	3/32 − .088	7/64 − .106	9/64 − .134
5/8″	.011	1/64 + .022	1/32 + .033	3/64 + .055	5/64 − .077	7/64 + .110	9/64 − .133	11/64 − .167
3/4″	.013	1/32 − .026	3/64 − .039	1/16 + .066	3/32 − .092	1/8 + .132	5/32 + .159	13/64 − .201
7/8″	1/64 − .015	1/32 − .031	3/64 − .046	5/64 − .077	7/64 − .107	5/32 − .154	3/16 − .186	15/64 + .234
1″	1/64 + .017	1/32 + .035	3/64 + .052	3/32 − .087	1/8 − .123	11/64 + .176	7/32 − .213	17/64 + .268
Depth*	1°	2°	3°	5°	7°	10°	12°	15°

carbon than 4 30 per cent but greater than 2 00 per cent, hyper-eutectoid containing less than 2.00 per cent carbon but greater than 0 80 per cent and hypo-eutectoid containing under 0.80 per cent The vast majority of steels used in the production of forgings fall into the hypo-eutectoid classification

From the iron-carbon diagram, it is possible, knowing the carbon content, to determine the temperatures for various structural compositions, thus the diagram becomes a working tool, to select the critical temperatures of a carbon grade of steel to obtain the desired phase changes by the proper heat treatment.

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WEIGHT OF DIE BLOCKS IN RELATION TO HAMMER RATING

AVERAGES OF THE WEIGHT IN POUNDS OF A SINGLE DIE BLOCK AS USED ON DIFFERENT SIZES OF BOARD AND STEAM DROP HAMMERS

Board Hammers		Steam Hammers	
Weight of Hammer	Weight of Block	Weight of Hammer	Weight of Block
600	50	800	300
800	110	1000	400
1000	170	1200	500
1200	230	1500	600
1500	320	2000	750
1600	350	2500	950
1800	410	3000	1100
2000	470	3500	1300
2500	630	4000	1500
3000	800	5000	1900
3500	960	6000	2400
4000	1130	8000	3400
5000	1330	10000	4500
		12000	5600
		16000	8000

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Useful Information

To find the circumference of a circle, multiply the diameter by 3.1416.

To find the diameter of a circle, multiply the circumference by .31831.

To find the area of a circle, multiply the square of the diameter by .7854.

The radius of a circle × 6.283185 = the circumference.

The square of the circumference of a circle × .07958 = the area.

Half the circumference of a circle × half its diameter = the area.

The circumference of a circle × .159155 = the radius.

The square root of the area of a circle × .56419 = the radius.

The square root of the area of a circle × 1.12838 = the diameter.

To find the diameter of a circle equal in area to a given square, multiply a side of the square by 1.12838.

To find the side of a square equal in area to a given circle, multiply the diameter by .8862.

To find the side of a square inscribed in a circle, multiply the diameter by .7071.

To find the side of a hexagon inscribed in a circle, multiply the diameter of the circle by .500.

To find the diameter of a circle inscribed in a hexagon, multiply a side of the hexagon by 1.7321.

To find the side of an equilateral triangle inscribed in a circle, multiply the diameter of the circle by .866.

To find the diameter of a circle inscribed in an equilateral triangle, multiply a side of the triangle by .57735.

To find the area of the surface of a ball (sphere), multiply the square of the diameter by 3.1416.

To find the volume of a ball (sphere), multiply the cube of the diameter by .5236.

Doubling the diameter of a pipe increases its capacity four times.

To find the pressure in pounds per square inch at the base of a column of water, multiply the height of the column in feet by .433.

A gallon of water (U. S. Standard) weighs 8.336 pounds and contains 231 cubic inches. A cubic foot of water contains 7½ gallons, 1728 cubic inches, and weighs 62.425 pounds at a temperature of about 39° F.

These weights change slightly above and below this temperature.

Tables and Data

In accordance with the standard practice approved by the American Standards Association, the ratio 25.4 mm = 1 inch is used for converting millimeters to inches. This factor varies only two millionths of an inch from the more exact factor 25.40005 mm, a difference so small as to be negligible for industrial length measurements.

Metric Measures

The metric unit of length is the meter = 39.37 inches.

The metric unit of weight is the gram = 15.432 grains.

The following prefixes are used for sub-divisions and multiples: Milli = $\frac{1}{1000}$, Centi = $\frac{1}{100}$, Deci = $\frac{1}{10}$, Deca = 10, Hecto = 100, Kilo = 1000, Myria = 10,000.

Metric and English Equivalent Measures

MEASURES OF LENGTH

Metric		*English*
1 meter	=	39.37 inches, or 3.28083 feet, or 1.09361 yards
.3048 meter	=	1 foot
1 centimeter	=	.3937 inch
2.54 centimeters	=	1 inch
1 millimeter	=	.03937 inch, or nearly 1-25 inch
25.4 millimeters	=	1 inch
1 kilometer	=	1093.61 yards, or 0.62137 mile

MEASURES OF WEIGHT

Metric		*English*
1 gram	=	15.432 grains
.0648 gram	=	1 grain
28.35 grams	=	1 ounce avoirdupois
1 kilogram	=	2.2046 pounds
4536 kilogram	=	1 pound
1 metric ton 1000 kilograms	=	.9842 ton of 2240 pounds 19 68 cwt. 2204 6 pounds
1.016 metric tons 1016 kilograms	=	1 ton of 2240 pounds

MEASURES OF CAPACITY

Metric		*English*
1 liter (= 1 cubic decimeter)	=	61.023 cubic inches .03531 cubic foot .2642 gal. (American) 2.202 lbs of water at 62° F.
28.317 liters	=	1 cubic foot
3.785 liters	=	1 gallon (American)
4.543 liters	=	1 gallon (Imperial)

Tables and Data

English Conversion Table

Length				
Inches	×	.0833	=	feet
Inches	×	.02778	=	yards
Inches	×	.00001578	=	miles
Feet	×	.3333	=	yards
Feet	×	.0001894	=	miles
Yards	×	36.00	=	inches
Yards	×	3 00	=	feet
Yards	×	0005681	=	miles
Miles	×	63360 00	=	inches
Miles	×	5280 00	=	feet
Miles	×	1760 00	=	yards
Circumference of circle	×	3188	=	diameter
Diameter of circle	×	3 1416	=	circumference
Area				
Square inches	×	.00694	=	square feet
Square inches	×	0007716	=	square yards
Square feet	×	144 00	=	square inches
Square feet	×	11111	=	square yards
Square yards	×	1296 00	=	square inches
Square yards	×	9 00	=	square feet
Dia. of circle squared	×	7854	=	area
Dia. of sphere squared	×	3 1416	=	surface
Volume				
Cubic inches	×	.0005787	=	cubic feet
Cubic inches	×	.00002143	=	cubic yards
Cubic inches	×	004329	=	U. S. gallons
Cubic feet	×	1728 00	=	cubic inches
Cubic feet	×	03704	=	cubic yards
Cubic feet	×	7 4805	=	U. S. gallons
Cubic yards	×	46656 00	=	cubic inches
Cubic yards	×	27 00	=	cubic feet
Dia. of sphere cubed	×	5236	=	volume
Weight				
Grains (avoirdupois)	×	.002286	=	ounces
Ounces (avoirdupois)	×	0625	=	pounds
Ounces (avoirdupois)	×	.00003125	=	tons
Pounds (avoirdupois)	×	16 00	=	ounces
Pounds (avoirdupois)	×	.01	=	hundredweight
Pounds (avoirdupois)	×	0005	=	tons
Tons (avoirdupois)	×	32000 00	=	ounces
Tons (avoirdupois)	×	2000 00	=	pounds

English Conversion Table

Energy

Horsepower	×	33000.	=ft.-lbs. per min.
B. t. u.	×	778.26	=ft.-lbs.
Ton of refrigeration	×	200.	=B. t. u. per min.

Pressure

Lbs. per sq. in.	×	2.31	= ft. of water (60°F.)
Ft .of water (60°F.)	×	.433	= lbs. per sq. in.
Ins. of water (60°F.)	×	.0361	= lbs. per sq. in.
Lbs. per sq. in.	×	27.70	= ins. of water (60°F.)
Lbs. per sq. in.	×	2.041	= ins. of Hg. (60°F.)
Ins. of Hg (60°F.)	×	.490	= lbs. per sq. in.

Power

Horsepower	×	746.	= watts
Watts	×	.001341	= horsepower
Horsepower	×	42.4	= B. t. u. per min.

Water Factors (at point of greatest density—39.2°F)

Miners inch (of water)	×	8.976	= U. S .gals. per min.
Cubic inches (of water)	×	.57798	= ounces
Cubic inches (of water)	×	.036124	= pounds
Cubic inches (of water)	×	.004329	= U. S. gallons
Cubic inches (of water)	×	.003607	= English gallons
Cubic feet (of water)	×	62.425	= pounds
Cubic feet (of water)	×	.03121	= tons
Cubic feet (of water)	×	7.4805	= U. S. gallons
Cubic feet (of water)	×	6.232	= English gallons
Cubic foot of ice	×	57.2	= pounds
Ounces (of water)	×	1 73	= cubic inches
Pounds (of water)	×	26 68	= cubic inches
Pounds (of water)	×	.01602	= cubic feet
Pounds (of water)	×	.1198	= U. S. gallons
Pounds (of water)	×	.0998	= English gallons
Tons (of water)	×	32 04	= cubic feet
Tons (of water)	×	239 6	= U. S. gallons
Tons (of water)	×	199.6	= English gallons
U. S. gallons	×	231.00	= cubic inches
U. S. gallons	×	.13368	= cubic feet
U. S. gallons	×	8 345	= pounds
U. S. gallons	×	.8327	= English gallons
U. S. gallons	×	3.785	= liters
English gallons (Imperial)	×	277.41	= cubic inches
English gallons (Imperial)	×	.1605	= cubic feet
English gallons (Imperial)	×	10 02	= pounds
English gallons (Imperial)	×	1 201	= U. S. gallons
English gallons (Imperial)	×	4 546	= liters

Metric Conversion Table

Length

Millimeters	×	.03937	=	inches
Millimeters	+	25.4	=	inches
Centimeters	×	.3937	=	inches
Centimeters	+	2.54	=	inches
Meters	×	39.37	=	inches (Act. Cong.)
Meters	×	3.281	=	feet
Meters	×	1.0936	=	yards
Kilometers	×	.6214	=	miles
Kilometers	+	1.6093	=	miles
Kilometers	×	3280.8	=	feet

Area

Sq. Millimeters	×	.00155	=	sq. in.
Sq. Millimeters	+	645.2	=	sq. in.
Sq. Centimeters	×	.155	=	sq. in.
Sq. Centimeters	+	6.452	=	sq. in.
Sq. Meters	×	10 764	=	sq. ft.
Sq. Kilometers	×	247.1	=	acres
Hectares	×	2.471	=	acres

Volume

Cu. Centimeters	+	16 387	=	cu. in.
Cu. Centimeters	+	3.69	=	fl. drs. (U.S.P.)
Cu. Centimeters	+	29.57	=	fl. oz. (U.S.P.)
Cu. Meters	×	35.314	=	cu. ft.
Cu. Meters	×	1.308	=	cu. yards
Cu. Meters	×	264.2	=	gals. (231 cu. in.)
Litres	×	61.023	=	cu. in. (Act. Cong.)
Litres	×	33.82	=	fl. oz. (U.S.P.)
Litres	×	.2642	=	gals. (231 cu. in.)
Litres	+	3.785	=	gals. (231 cu. in.)
Litres	+	28.317	=	cu. ft.
Hectolitres	×	3.531	=	cu. ft.
Hectolitres	×	2.838	=	bu. (2150.42 cu. in.)
Hectolitres	×	.1308	=	cu. yds.
Hectolitres	×	26.42	=	gals. (231 cu. in.)

Weight

Grams	×	15.432	=	grains (Act. Cong.)
Grams	+	981.	=	dynes
Grams (water)	+	29.57	=	fl. oz.
Grams	+	28.35	=	oz. avoirdupois
Kilo-grams	×	2.2046	=	lbs.

Metric Conversion Table (Cont.)

Weight

Kilo-grams	×	35.27	= oz. avoirdupois
Kilo-grams	×	.0011023	= tons (2000 lbs.)*
Tonneau (Metric ton)	×	1.1023	= tons (2000 lbs.)
Tonneau (Metric ton)	×	2204.6	= lbs.

Unit Weight

Grams per cu. cent.	÷	27.68	= lbs. per cu. in.
Kilo per meter	×	.672	= lbs per ft.
Kilo per cu. meter	×	06243	= lbs per cu. ft.
Kilo per Cheval	×	2 235	= lbs per h. p.
Grams per liter	×	.06243	= lbs. per cu. ft.

Pressure

Kilo-grams per sq. cm.	×	14 223	= lbs per sq in.
Kilo-grams per sq. cm.	×	32 843	= ft of water (60°F.)
Atmospheres (international)	×	14 696	= lbs per sq in

Energy

Joule	×	.7376	= ft. lbs.
Kilo-gram meters	×	7.233	= ft. lbs.

Power

Cheval vapeur	×	9863	= h. p.
Kilo-watts	×	1 341	= h p.
Watts	÷	746	= h p.
Watts	×	.7373	= ft. lbs. per sec

Miscellaneous

Kilogram calorie	×	3.968	= B. t. u.
Standard gravity (Sea level 45° lat.)	÷	980.665	= centimeters per sec. per sec.
Frigories/hr. (French)	÷	3023.9	= Tons refrigeration

Tables and Data

The following pages show temperatures on Fahrenheit and Centigrade thermometers.

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales

Fahrenheit Degs	Centigrade Degs.	Fahrenheit Degs	Centigrade Degs	Fahrenheit Degs	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
—459 4	—273	—21	—29.4	17 6	—8.		13.3
—436	—270.	—20 2	—29.	18.	—7 8		13 9
—418	—260.	—20.	—28 9	19.	—7 2		14.
—400	—240	—19.	—28 3	19 4	—7.		14 4
—382.	—230	—18 4	—28.	20.	—6 7		15.
—364.	—220.	—18.	—27 8	21.	—6 1		15 6
—346.	—210	—17.	—27 2	21 2	—6.		16.
—328	—200	—16 6	—27.	22.	—5 6		16 1
—310	—190	—16.	—26 7	23.	—5		16 7
—292	—180.	—15.	—26 1	24.	—4 4		17.
—274.	—170.	—14 8	—26.	24 8	—4.		17 2
—256.	—160	—14.	—25 6	25.	—3 9		17.8
—238.	—150.	—13.	—25.	26.	—3 3		18.
—220	—140	—12.	—24 4	26 6	—3.		18.3
—202	—130	—11 2	—24.	27.	—2 8		18 9
—184.	—120	—11.	—23 9	28.	—2 2		19.
—166	—110	—10.	—23 3	28 4	—2.		19 4
—148.	—100	— 9 4	—23.	29.	—1 7		20.
—139.	— 95	— 9.	—22 8	30.	—1 1		20 6
—130	— 90	— 8.	—22 2	30 2	—1.	69 8	21.
—121.	— 85	— 7 6	—22.	31.	—0.6		21.1
—112	— 80	— 7.	—21.7	32.	0.		21 7
—103	— 75	— 6.	—21 1	33.	+0 6		22.
— 94.	— 70	— 5 8	—21.	33 8	1.		22 2
— 85.	— 65	— 5.	—20 6	34.	1 1		22.8
— 76	— 60	— 4.	—20.	35.	1 7		23.
— 67.	— 55	— 3.	—19.4	35 6	2.		23 3
— 58	— 50	— 2 2	—19.	36.	2 2		23 9
— 49	— 45	— 2.	—18 9	37.	2 8		24.
— 40.	— 40.	— 1.	—18 3	37.4	3.		24.4
— 39.	— 39 4	— 0 4	—18.	38.	3 3		25.
— 38 2	— 39.	0.	—17 8	39.	3 9		25 6
— 38.	— 38.9	+ 1.	—17.2	39 2	4.		26.
— 37.	— 38 3	1.4	—17.	40.	4 4		26.1
— 36 4	— 38.	2.	—16 7	41.	5.		26 7
— 36.	— 37.8	3.	—16 1	42.	5 6		27.
— 35.	— 37 2	3.2	—16.	42 8	6.		27.2
— 34 6	— 37.	4.	—15.6	43.	6 1		27 8
— 34.	— 36 7	5.	—15.	44.	6 7		28.
— 33.	— 36 1	6.	—14 4	44 6	7.		28 3
— 32 8	— 36.	6 8	—14.	45.	7 2		28 9
— 32.	— 35 6	7.	—13 9	46.	7.8		29.
— 31.	— 35.	8.	—13 3	46 4	8.		29 4
— 30.	— 34 4	8 6	—13.	47.	8 3		30.
— 29 2	— 34.	9.	—12 8	48.	8 9		30 6
— 29.	— 33 9	10.	—12 2	48 2	9.		31.
— 28.	— 33.3	10 4	—12.	49.	9 4		31.1
— 27.4	— 33.	11.	—11 7	50.	10.		31.7
— 27.	— 32.8	12.	—11 1	51.	10.6		32.
— 26.	— 32 2	12 2	—11.	51.8	11.		32.2
— 25.6	— 32.	13.	—10.6	52.	11 1		32 8
— 25.	— 31 7	14.	—10.	53.	11 7		33.
— 24.	— 31 1	15.	— 9 4	53.6	12.		33 3
— 23.8	— 31.	15 8	— 9.	54.	12.2		33.9
— 23.	— 30 6	16.	— 8 9	55.	12 8		34.
— 22.	— 30.	17.	— 8 3	55.4	13.		34 4

Equivalent Temperature Readings for Fahrenheit and Centigrade Scales

Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.	Fahrenheit Degs.	Centigrade Degs.
95.	35.	134.	56.7	172.4	78.	211.	99.4
96.	35.6	134.6	57.	173.	78.3	212.	100.
96.8	36.	135.	57.2	174.	78.9	213.	100.6
97.	36.1	136.	57.8	174.2	79.	213.8	101.
98.	36.7	136.4	58.	175.	79.4	214.	101.1
98.6	37.	137.	58.3	176.	80.	215.	101.7
99.	37.2	138.	58.9	177.	80.6	215.6	102.
100.	37.8	138.2	59.	177.8	81.	216.	102.2
100.4	38.	139.	59.4	178.	81.1	217.	102.8
101.	38.3	140.	60.	179.	81.7	217.4	103.
102.	38.9	141.	60.6	179.6	82.	218.	103.3
102.2	39.	141.8	61.	180.	82.2	219.	103.9
103.	39.4	142.	61.1	181.	82.8	219.2	104.
104.	40.	143.	61.7	181.4	83.	220.	104.4
105.	40.6	143.6	62.	182.	83.3	221.	105.
105.8	41.	144.	62.2	183.	83.9	222.	105.6
106.	41.1	145.	62.8	183.2	84.	222.8	106.
107.	41.7	145.4	63.	184.	84.4	223.	106.1
107.6	42.	146.	63.3	185.	85.	224.	106.7
108.	42.2	147.	63.9	186.	85.6	224.6	107.
109.	42.8	147.2	64.	186.8	86.	225.	107.2
109.4	43.	148.	64.4	187.	86.1	226.	107.8
110.	43.3	149.	65.	188.	86.7	226.4	108.
111.	43.9	150.	65.6	188.6	87.	227.	108.3
111.2	44.	150.8	66.	189.	87.2	228.	108.9
112.	44.4	151.	66.1	190.	87.8	228.2	109.
113.	45.	152.	66.7	190.4	88.	229.	109.4
114.	45.6	152.6	67.	191.	88.3	230.	110.
114.8	46.	153.	67.2	192.	88.9	231.	110.6
115.	46.1	154.	67.8	192.2	89.	231.8	111.
116.	46.7	154.4	68.	193.	89.4	232.	111.1
116.6	47.	155.	68.3	194.	90.	233.	111.7
117.	47.2	156.	68.9	195.	90.6	233.6	112.
118.	47.8	156.2	69.	195.8	91.	234.	112.3
118.4	48.	157.	69.4	196.	91.1	235.	112.8
119.	48.3	158.	70.	197.	91.7	235.4	113.
120.	48.9	159.	70.6	197.6	92.	236.	113.3
120.2	49.	159.8	71.	198.	92.2	237.	113.9
121.	49.4	160.	71.1	199.	92.8	237.2	114.
122.	50.	161.	71.7	199.4	93.	238.	114.4
123.	50.6	161.6	72.	200.	93.3	239.	115.
123.8	51.	162.	72.2	201.	93.9	240.	115.6
124.	51.1	163.	72.8	201.2	94.	240.8	116.
125.	51.7	163.4	73.	202.	94.4	241.	116.1
125.6	52.	164.	73.3	203.	95.	242.	116.7
126.	52.2	165.	73.9	204.	95.6	242.6	117.
127.	52.8	165.2	74.	204.8	96.	243.	117.2
127.4	53.	166.	74.4	205.	96.1	244.	117.8
128.	53.3	167.	75.	206.	96.7	244.4	118.
129.	53.9	168.	75.6	206.6	97.	245.	118.3
129.2	54.	168.8	76.	207.	97.2	246.	118.9
130.	54.4	169.	76.1	208.	97.8	246.2	119.
131.	55.	170.	76.7	208.4	98.	247.	119.4
132.	55.6	170.6	77.	209.	98.3	248.	120.
132.8	56.	171.	77.2	210.	98.9	249.	120.6
133.	56.1	172.	77.8	210.2	99.	249.8	121.